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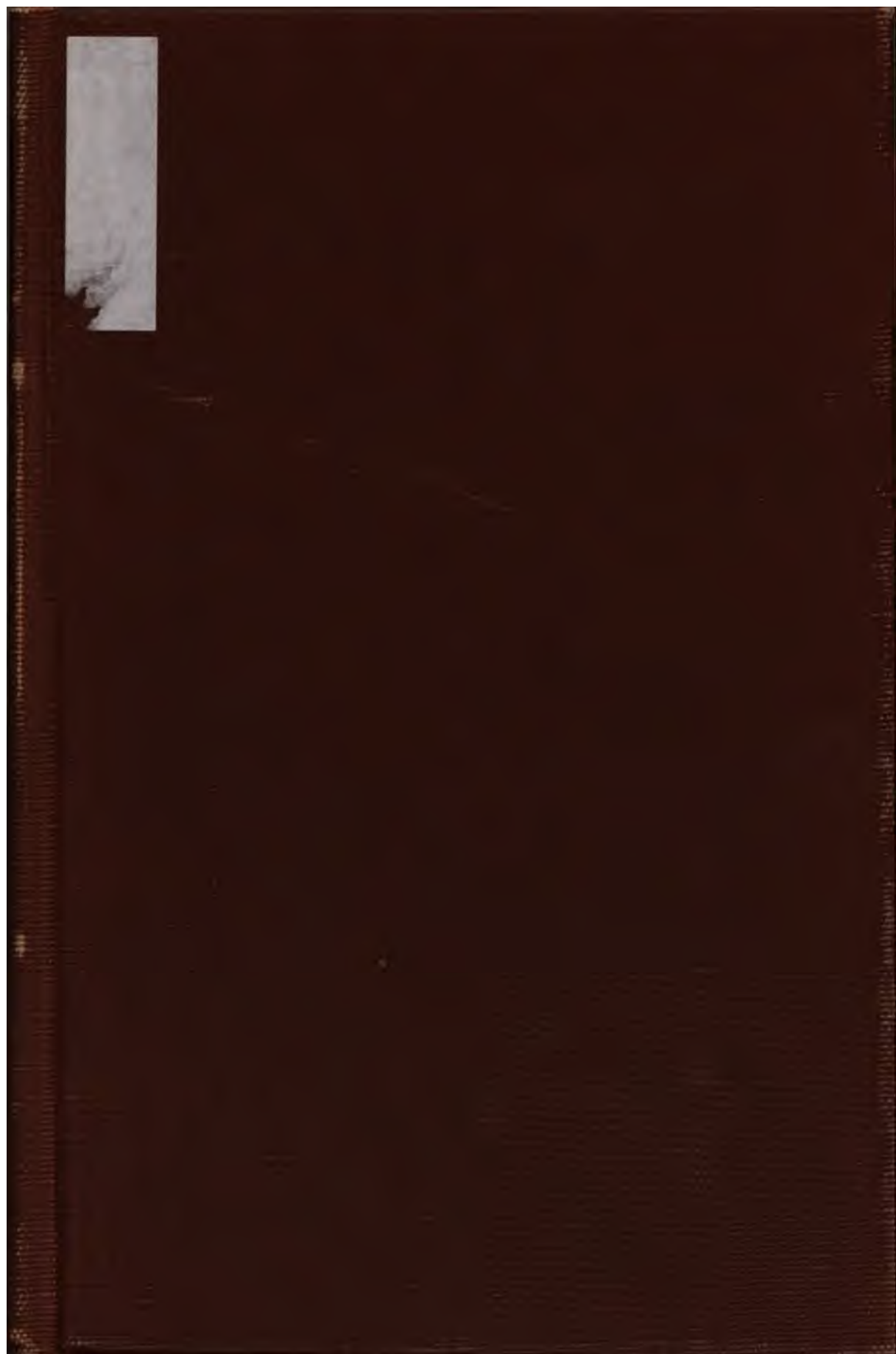
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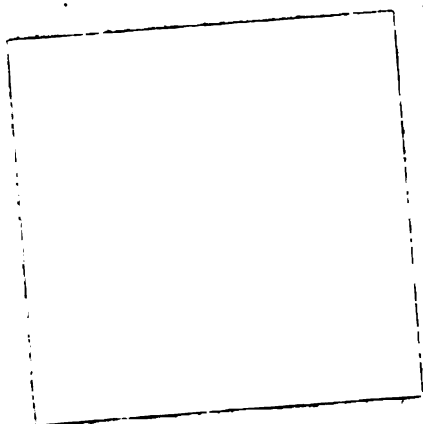
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UNITED STATES GEOLOGICAL SURVEY

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Bulletin 680

A GEOLOGIC RECONNAISSANCE FOR PHOSPH
AND COAL IN SOUTHEASTERN IDAHO
AND WESTERN WYOMING

BY

ALFRED REGINALD SCHULTZ



WASHINGTON

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A GEOLOGIC RECONNAISSANCE FOR PHOSPHATE AND COAL IN SOUTHWESTERN IDAHO AND WESTERN WYOMING.

By ALFRED REGINALD SCHULTZ.

INTRODUCTION.

PURPOSE OF INVESTIGATION.

A reconnaissance examination of a part of southeastern Idaho and western Wyoming lying between meridians $110^{\circ} 45'$ and 112° and parallels 43° and 44° , comprising an area of approximately 2,000 square miles in the vicinity of Big Bend of South Fork of Snake River, was undertaken in 1912, for the purpose of collecting data for the elimination of lands from existing phosphate reserves if it was found that they contained no valuable deposits of phosphate. The writer spent three weeks in the region north of Snake River and north of the area examined in a reconnaissance by Schultz and Richards ¹ in the autumn of 1911. As a result of this examination 141,287 acres of withdrawn phosphate land was restored to agricultural entry. The data collected during the examination indicate that only a part of the phosphate land in this region was included in the phosphate reserves created by the withdrawals of December, 1908, December, 1909, and July 2, 1910. The former boundary of the phosphate reserve in this region has therefore been so modified and extended as to include all the known phosphate areas. This has necessitated the withdrawal of 84,507 acres, leaving a net reduction in the outstanding Idaho phosphate withdrawals of 56,780 acres as a result of this preliminary examination. The withdrawn lands have been included in the phosphate reserve because it is known that they are underlain by phosphate deposits. It was found to be impossible during this short reconnaissance examination to trace the outcrops of the phosphate beds throughout the area, measure the thickness of the phosphate beds at short intervals, determine the amount of phosphoric acid they contain, measure the thickness of the overlying beds, and work out the structure in sufficient detail to determine in what tracts the phosphate beds occur near enough

¹ Schultz, A. R., and Richards, R. W., A geologic reconnaissance in southeastern Idaho: U. S. Geol. Survey Bull. 530, pp. 267-284, 1913.

to the surface to justify the classification of the tracts as phosphate land. As more detailed examinations of these lands are made, part of the area now withdrawn will no doubt be classified as non-

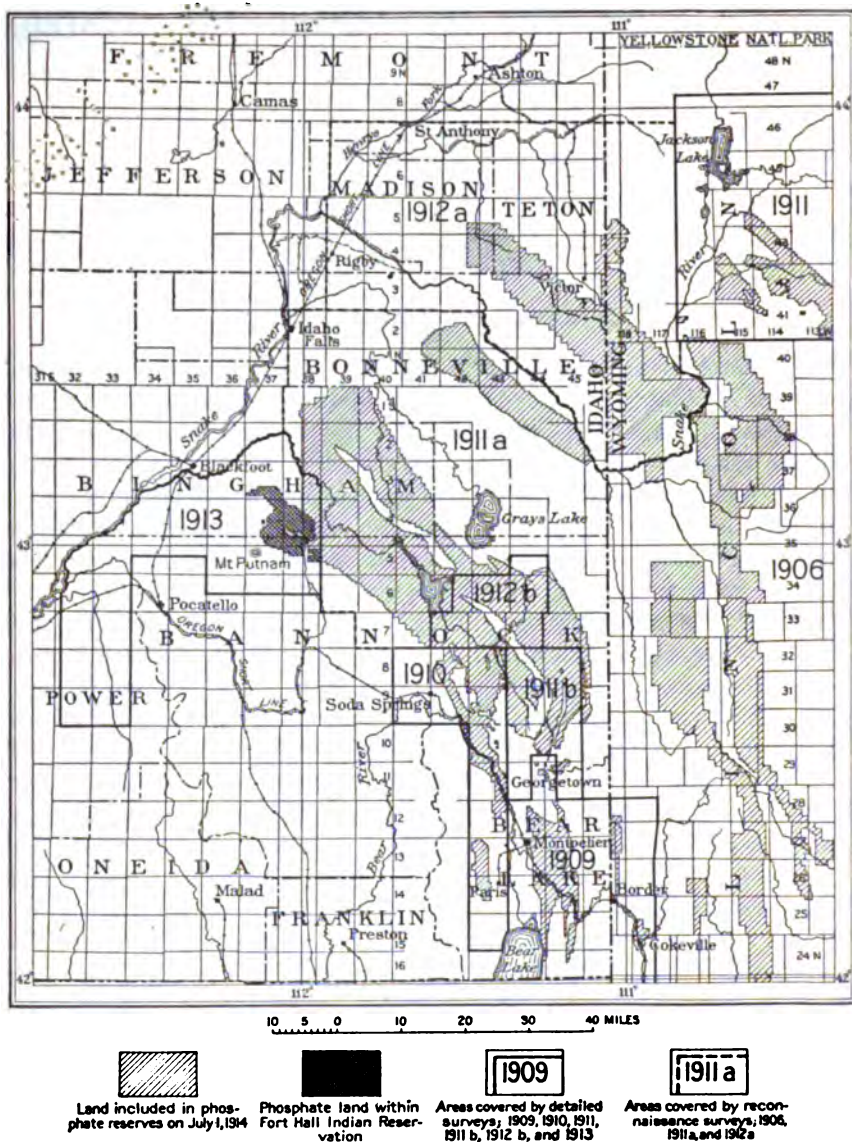


FIGURE 1.—Map showing areas examined by the United States Geological Survey and the extent of phosphate reserves in eastern Idaho and western Wyoming on July 1, 1914.

phosphate, and small outliers of phosphate rock may be found capping the ridges or included between fault blocks in areas not included in the outstanding phosphate reserves. Figure 1 shows the extent of the phosphate reserves on July 1, 1914, and the areas

in the phosphate region in southeastern Idaho and western Wyoming examined by the Survey since 1909, when the first extensive mapping of the phosphate deposits in the Rocky Mountain region was undertaken.

EARLIER WORK.

The first geologic and topographic examination in the area considered in this report was made in 1872, when the Snake River division of the Hayden Survey traversed the country from Ogden, Utah, to Fort Hall, Idaho; thence went up Snake River and the valley of Henrys Fork to its head, where an examination of the lakes, geysers, and headwaters of the Fire Hole Basin and vicinity were made; thence crossed the divide to the headwaters of South Fork of Snake River and went down that stream by way of Jackson Lake and the canyon of the South Fork to its emergence on the great lava-covered plains a few miles north of Fort Hall, Idaho. The geologic report by Frank H. Bradley¹ and the accompanying maps set forth admirably the general features along the route of travel and give much information that is of value in interpreting the structure of the region.

The entire area covered in the present reconnaissance survey was mapped topographically by the Hayden Survey in 1877, and a considerable part of the area was examined geologically by Orestes St. John,² whose report includes a fund of accurate information and represents reconnaissance work of high standard. In accuracy and quantity the data given in the text are well in advance of the geologic maps which accompany them. To the errors in the maps and in the interpretation of the structure are due in part the mislocation of the phosphate reserves as originally constituted, and one of the main results of the present examination consists in corrections of the errors in these old maps and information on the localities not visited by St. John or members of his geologic party.

More recently part of the area was examined by members of the United States Geological Survey. In 1906 the writer³ and party, while making a reconnaissance examination of the deposits of central Lincoln County, Wyo., examined a portion of the area east of the Absaroka fault and south of Snake River. In the summer of 1910 Eliot Blackwelder⁴ and party traversed the region from Montpelier, Idaho, northeastward across the Preuss Mountains to Afton, Wyo., thence northward along the Salt River valley to Snake River, thence

¹ U. S. Geol. Survey Terr. Sixth Ann. Rept., pp. 189-271, 1873.

² U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 321-508, 1879.

³ Schuch, A. R., Coal fields in a portion of central Uinta County, Wyo.: U. S. Geol. Survey Bull. 316, pp. 212-219, 1907; Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 323, 1914.

⁴ Blackwelder, Eliot, A reconnaissance of the phosphate deposits in western Wyoming: U. S. Geol. Survey Bull. 470, pp. 453-481, 1911.

down the Snake River valley to Irwin, Idaho, and across the Snake River Range to Victor, Idaho, in the Teton Basin. Only cursory observations were made along the route from Montpelier to Victor, but on the west side of the Teton Range the party spent several days in more systematic geologic work. A similar study was made of the mountains south and east of Jackson Hole, including the canyon of Snake River in Wyoming. In the summer of 1912 Blackwelder again visited the region and made an examination of the rocks along the west side of the Teton Mountains from the Yellowstone National Park southward as far as Darby Creek, in the Teton Basin, but the results of this investigation have not yet been published. In the fall of the same year E. G. Woodruff examined some of the coal beds in the vicinity of Horseshoe and Packsaddle creeks, on the northeast slope of the Bighole Mountains west of Driggs, Idaho.¹

GEOGRAPHY.

ITINERARY.

In making the reconnaissance examination of the withdrawn phosphate lands in the Snake River, Bighole, and Teton mountains the party moved by rapid stages from the railway at Rexburg, Idaho, southeastward across the lava-covered plains to Snake River; thence southeastward to the mouth of the Snake River canyon near the State boundary, a few miles east of the Salt River valley. Along the route of travel only cursory observations were made, but on Snake River above the mouth of the canyon several days were spent in more systematic geologic work, in examining sections and making traverses, which proved beyond question that the phosphate beds are present in the hills on each side of Snake River and have been eroded in the valleys, for they occur at no place along Snake River from the lower end of the canyon eastward to the Absaroka fault. Similar studies were made of the mountains at a number of places across the range from Snake River northwestward to Moody Creek, southeast of Rexburg. Several days were spent in a study of the geology of the mountains along Indian, Elk, Palisade, Rainy, and Pine creeks. The party then moved across the Snake River Range over the divide at the head of Pine Creek into Teton Basin, where cursory examinations were made along the east flank of the Bighole Mountains southwest of Victor, Idaho, and along the west flank of the Teton Mountains east of Victor, in the vicinity of Moose, Fox, and Darby creeks. From Victor the party moved northwestward along the east base of the Bighole Mountains to Horseshoe Creek, where a somewhat more detailed study of the Bighole Mountains was made. Owing to the heavy fall of snow at this time, which

¹ Woodruff, E. G., *The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho* U. S. Geol. Survey Bull. 541, pp. 379-388, 1914.

completely masked the geologic formations exposed in the mountains, the work was discontinued, and the party returned to Rexburg over the lava-covered plains by way of Canyon Creek and the village of Teton.

TOPOGRAPHY AND SETTLEMENT.

The entire area examined lies within the Snake River drainage basin. The drainage has a dominant northwesterly trend and is carried by Snake River, which in the eastern part of the area flows in a southerly direction and south of Jackson Hole goes between the Snake River and Salt River ranges in a deep canyon at nearly right angles to the trend of the mountains and thence flows northwest. The principal tributaries are Gros Ventre, Hoback, Greys, and Salt rivers and Henrys Fork. Teton River is the largest tributary of Henrys Fork and drains all of Teton Basin.

Two types of country are included in the area examined—lava plains or plateaus and the rugged mountain tracts which are made up for the most part of deformed sandstone and limestone and metamorphosed schists, granites, and gneisses of pre-Cambrian age. With the exception of the northwestern part of the area, north and west of the Bighole Mountains, Teton Basin, and part of Snake River valley, the entire area is one of ragged, well-forested mountains. On the east side of the area the ranges trend nearly due north; in the central and western portions they run northwest. The mountain ranges are generally separated by narrow valleys, but some of the intervening spaces are wide, flat-bottomed basins, such as Teton Basin and Swan Valley Basin in Idaho, and Jackson Hole, on Snake River, and Star Valley, on Salt River, in western Wyoming. These larger valleys, as well as the lava-covered plains in the northwestern part of the area, are now fairly well settled by ranchmen and dry farmers, but in the mountain districts there are few inhabitants and no settlements of importance. A considerable part of the area is included in the Palisade, Teton, and Caribou national forests, and is primarily used for cattle and sheep grazing during the summer and as a source of timber. The mountainous portion, especially in the vicinity of Jackson Hole, is a celebrated game country that has become noted for its elk and is visited annually by hundreds of hunters in search of big game. Trails and wagon roads are common throughout the area, and good hunting ground is readily accessible from all the settlements or larger valleys. The United States Forest Service in recent years has built excellent roads and trails in that portion included within the national forests.

The only railroad in this region is the Oregon Short Line, which crosses the northwestern part of the area at Rexburg and St. Anthony and has a spur line from Ashton to Victor, in the Teton Basin. The same company in the fall of 1912 completed a second survey of a

railroad route from Idaho Falls, Idaho, to Jackson, Wyo., along Snake River. The approximate location of this alinement survey is shown on Plate I by a black line. It was reported in 1912 that construction work on this line was to begin in the near future. Rexburg, St. Anthony, and Driggs, Idaho, and Jackson, Wyo., are the main trading points, although there are numerous small villages and trading posts scattered throughout the area. Post offices are maintained at many places in this area.

GEOLOGY.

STRATIGRAPHY.

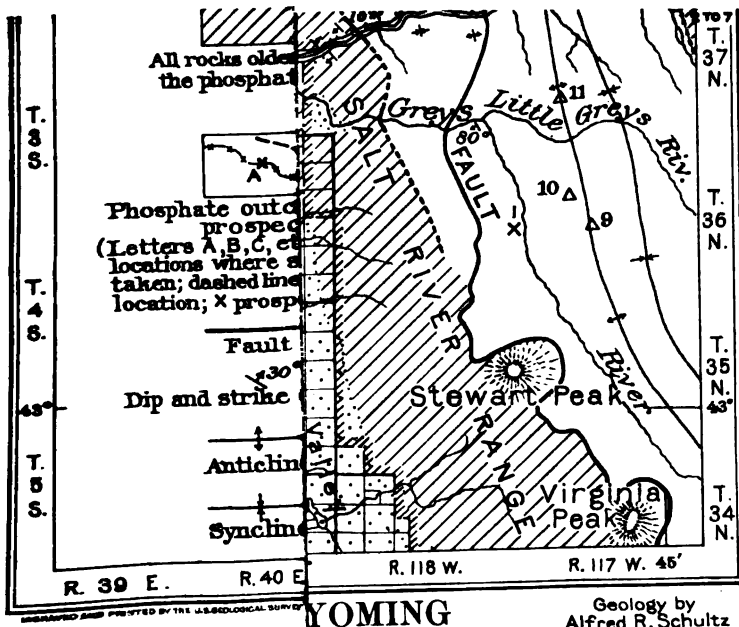
GENERAL SECTION.

The rocks of the region range in age from pre-Cambrian to Quaternary. The portion of the stratigraphic column from the pre-Cambrian basal complex to the Devonian appears to be only partly represented, as there are unconformities separating the Cambrian from the pre-Cambrian, the Ordovician from the Cambrian, the Silurian from the Ordovician, and the Devonian from the Silurian. The portion of the column above the Devonian appears to be more fully represented from the basal Carboniferous to the top of the Jurassic, where there is another pronounced unconformity. At or near the end of Cretaceous time there was an interval of erosion, which is indicated by a marked unconformity. Subsequent intervals of erosion resulted in unconformities in the Tertiary.

The main features of the section are set forth in the subjoined table.

Generalized section of sedimentary formations in southeastern Idaho and western Wyoming, in the area covered by this report.

System.	Series.	Group and formation.	Thickness.	Character of strata.	Remarks.
Quaternary.	Recent.		<i>Feet.</i> 0-250	Hill wash, talus, and landslide material.	Clay and soils derived largely from the weathering of underlying rocks. Good agricultural land.
			0-1,000	Valley fill, terraces, flood-plain deposits, small-stream bottom lands, and travertine.	
	.....		0-150	River terraces.	Gold placers worked along Snake River. Similar deposits of auriferous gravel occur both up and down Snake River beyond this area and on some of its tributaries.
	Pleistocene.		1-150	Boulders, gravel, and morainal material associated with hill wash.	



Generalized section of sedimentary formations in southeastern Idaho and western Wyoming, in the area covered by this report—Continued.

System.	Series.	Group and formation.	Thickness.	Character of strata.	Remarks.
Tertiary.	Pliocene (?)		Feet. (?)	Marls, marly limestones, and calcareous conglomerates.	No particular value.
	Eocene.	Unconformity			
		Wasatch group. Knight formation.	500±	Red and yellow sandy clays, shales sandstones, and concretionary limestones.	Occurs east Snake River.
		Unconformity Almy formation.	1,000±	Red and yellowish-white conglomerates, sandstones, and sandy clays.	Occurs east Snake River. Thickness not measured. Probable source water supply.
Cretaceous or Tertiary.	(?)	Evanston formation (?).	(?)	In southwestern Wyoming, gray, yellow, and black carbonaceous shales and clays interbedded with sandstones containing some coal.	May be present along Snake River. Coal bearing in southwestern Wyoming.
		Unconformity			
Cretaceous.	Upper Cretaceous.	Adaville formation (?).	(?)	White, yellow, and brown carbonaceous shales and sandstones in southwestern Wyoming.	Not recognized this field. May be present beneath lava cover. Coal bearing in southwestern Wyoming.
		Hilliard formation (?).	(?)	Gray and black sandy shales and sandstones in southwestern Wyoming. Weathers readily and affords a region of low relief.	Not recognized this field. May be present beneath lava cover.
		Frontier formation.	3,000±	Gray, buff, and yellow shales and sandstones, with coal beds. The shales and sandstones are soft and sandy and do not form pronounced ridges. Rocks are of Benton age.	Coal-bearing throughout western Wyoming and in eastern Idaho.
		Aspen formation.	1,000-1,200	Gray and black shales, shaly sandstones, and beds of compact gray sandstone, containing fish scales of Benton age.	Oil bearing in southwestern Wyoming. Not measured north and west of Snake River.
		Bear River formation.	800±	Black shale, shaly sandstone, and shaly limestone with abundant invertebrate fossils.	Coal bearing in southwestern Wyoming as in eastern Idaho. Coal beds are thin and impure to be of value.
		Unconformity			

Generalized section of sedimentary formations in southeastern Idaho and western Wyoming, in the area covered by this report—Continued.

System.	Series.	Group and formation.	Thickness.	Character of strata.	Remarks.
Jurassic.		Beckwith formation.	<i>Feet.</i> 900-4,000	White, gray, yellow, brown, and reddish-yellow shales and sandstones, with some limestones, red or gray conglomerates, and quartzite, containing Jurassic fossils.	Present throughout western Wyoming and eastern Idaho. Not measured north of Snake River.
		Twin Creek limestone.	800-1,200	Chiefly black, gray, and bluish-gray shaly limestones, the whole containing numerous Jurassic fossils.	Present throughout western Wyoming and eastern Idaho. Entire section not measured north of Snake River.
		Nugget sandstone	500-1,000	Yellow, white, and red quartzitic sandstones.	Prominent ridge maker throughout region.
Triassic.		(?)	200-500	Reddish-brown shale and shaly sandstone, with intercalated mottled limestone.	Has been prospected for copper in part of this region.
		Unconformity			
	Lower Triassic.	Thaynes limestone.	700-1,000	Yellow, gray, and blue cherty limestones, with some yellow sandstones. Bluish-gray limestones, very fossiliferous. Thin and thick bedded platy limestones.	Present throughout region.
		Woodside formation.	800-1,000	Red and pasty brown shaly sandstones and shales, intercalated with muddy limestone lentils.	Present throughout western Wyoming and eastern Idaho.
Carboniferous.	Permian.	Phosphoria formation.	75-400	Rex chert member and cherty limestones at top, over yellow to brown sandstones, brown to black shales, coaltic limestone, and phosphate rock.	Prospected for coal at many places in western Wyoming and eastern Idaho.
	Pennsylvanian	Wells formation.	300-1,000	Sandy limestones, calcareous sandstones, and variable quartzites. Includes the Weber quartzite and Tensleep sandstone as mapped in southern Idaho and western Wyoming.	This formation is present in western Wyoming and eastern Idaho, and has been mapped under various names whose limits are not the same. It probably includes both the Amaden and Morgan formations as mapped in some localities.

Generalized section of sedimentary formations in southeastern Idaho and western Wyoming, in the area covered by this report—Continued.

System.	Series.	Group and formation.	Thickness.	Character and strata.	Remarks.
Carboniferous.	Mississippian.	Brazer limestone.	<i>Feet.</i> 200-1,000	Gray to blue, thick-bedded limestones, some variegated reddish-gray shales, and calcareous sandstone.	Present throughout western Wyoming and eastern Idaho. In some localities this series of beds has been mapped as parts of Arnsden and Morgan formations.
		Madison limestone.	1,000	Dark gray to bluish limestones, thin-bedded in part but also massive.	Abundant marine fossils at many horizons.
Devonian.		Threeforks formation and Jefferson limestone.	350	Black, gray, and brown shales, dark limestones, and thin-bedded sandstones.	Upper 200 feet dark shale and thin-bedded limestone, probably represents the Threeforks formation. Lower 150 feet of massive crystalline limestone probably represents the Jefferson limestone.
		Unconformity			
Silurian.		Unconformity	50	Whitish-gray dolomite, thin bedded and brittle. Fragmentary fossils.	In places appears to be absent.
Ordovician.	Upper Ordovician.	Bighorn dolomite.	350	Gray to cream-colored dolomite with rough pitted surfaces.	Makes pronounced ridges and nearly perpendicular ledges.
		Unconformity			
Cambrian.	Upper Cambrian.	Gallatin limestone.	200	Gray oolitic and conglomeratic limestones with some shale. Limestones not as massive as overlying bed. Contain few fossils.	
	Middle Cambrian.	Gros Ventre formation.	500	Gray, brown, red, and green shales and thin-bedded limestones.	Weather readily and usually form low relief.
		Flathead quartzite.	250	Buff or pinkish sandstone and quartzite with some conglomerate.	
Pre-Cambrian.		Unconformity			
				Schists, granites, gneisses, and igneous rocks cut by dikes of pegmatite and diabase. Some of the schistose and gneissic rock may have a sedimentary origin.	Prospected for copper, silver, lead, and gold.

PRE-CAMBRIAN TO CARBONIFEROUS (PENNSYLVANIAN SERIES, INCLUSIVE).

GENERAL FEATURES.

In the extreme northeastern part of the area shown on the accompanying map lie the Teton Mountains. This range trends nearly north along the Idaho-Wyoming State line, lying chiefly in western Wyoming. It consists of a gentle westward-dipping monocline, crossed in the north by a low anticline that trends northwest and in the south by a low anticline that trends nearly due west and in its westward extension swings toward the northwest, nearly parallel to the Bighole Mountains. The strata in several places are broken by normal faults parallel to the monocline. Along the crest of the Teton monocline and also along the axis of the northern transverse anticline the pre-Cambrian granite, gneiss, and schistose rocks are exposed. Against these older rocks on the southwest flank of the range rests a comprehensive sequence of Paleozoic strata, ranging in age from Cambrian to Carboniferous. The same rocks reappear on the northeast side of the transverse anticline. All the beds along this range, from pre-Cambrian to Carboniferous, were mapped and studied and detailed sections were measured by Eliot Blackwelder in 1912, while making a study of the Grand Teton quadrangle, but no report has yet been published.

In the course of this reconnaissance examination it has been found advisable for the small-scale map to group all the beds older than the Phosphoria formation, including the pre-Cambrian, Cambrian, Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian, into one map unit, and the Phosphoria formation and the pre-Quaternary beds younger than that formation, which range in age from Permian (late Carboniferous) to Tertiary, inclusive, into another map unit.

In the greater part of the region examined the area occupied by outcrops of the Permian, Triassic, and Jurassic formations practically represents the lands that were regarded in the field as containing phosphate deposits in large enough quantities and near enough to the surface to be eventually suitable for economic development. Some of the beds overlying the phosphate deposits tend to become thinner toward the north, in eastern Idaho and western Wyoming, and in this part of the region the area that contains phosphate deposits within workable depth susceptible of economic development is probably represented by the outcrop of the beds from the Phosphoria formation up to the Beckwith formation, including the Twin Creek limestone and a considerable portion of the Beckwith.

The general distribution of the rocks older than the Phosphoria formation is shown on the accompanying map by one pattern, without any attempt to indicate the distribution of the several forma-

tions, and the distribution of the Phosphoria formation and younger pre-Quaternary beds is shown by the absence of a geologic pattern. Detailed examinations are needed to work out the distribution and thickness of the Phosphoria formation, which contains the phosphate beds, and the Frontier and Bear River formations, which contain the coal beds. The Quaternary deposits, exclusive of the glacial material, which is not mapped, are shown by a different pattern on the map.

PRE-CAMBRIAN ROCKS.

The oldest rocks that underlie the Paleozoic sedimentary series in this region consist of pre-Cambrian crystalline gneisses, granite, and schists of various kinds. This basal complex is composed largely of igneous rock, although some of the schistose and gneissic rocks may have had a sedimentary origin. The gneisses are in part coarsely crystalline, and the entire series shows the effect of metamorphism by pressure and is in places intricately folded and traversed by dikes of pegmatite and diabase. The age of this complex has heretofore been regarded as Archean, but the reasons for this assignment are not entirely satisfactory. Rocks of Algonkian age are represented in many parts of the Rocky Mountain province and may in part be represented in the intensely mashed and metamorphosed components of this basal complex. For the present, therefore, or until much more detailed work has been done, it seems advisable not to separate the rocks composing this basal complex, but to refer the entire series as a unit to the pre-Cambrian. Exposures of these older rocks occur in the northeastern part of the area here described and form the central and eastern parts of the Teton Mountains. More detailed studies will no doubt determine the age of these rocks and definitely assign them either to the Algonkian or Archean or to both.

CAMBRIAN SYSTEM.

Upon the basement complex of the Teton and associated ranges was deposited unconformably in Paleozoic time a great thickness of sandstone, limestone, and shale. These strata include the Cambrian, the lowest known sedimentary beds exposed, Ordovician, Silurian, Devonian, and Carboniferous. The basal beds of the Paleozoic sedimentary series were formed from the detrital material derived from the disintegration of the schist and gneiss that formed the old continental land mass. Some of the members of these sediments consist of soft, poorly cemented, imperfectly stratified material, composed of coarse vein quartz, feldspar, fine conglomerate, and fragments of the underlying crystalline rocks.

FLATHEAD QUARTZITE.

In the Teton region and elsewhere in Wyoming the Flathead quartzite is the lowest of the Cambrian formations and consists essentially of pale-brown to reddish sandstone and quartzite, varying considerably in character both horizontally and vertically. In places the beds are streaked and spotted with a dark-maroon color, due to the presence of ferric oxide. In many places the beds are firmly cemented and constitute a typical quartzite, which forms pronounced ridges and gives rise to reddish-tinged outcrops that are very conspicuous and readily distinguished from the overlying beds. Near the top of the formation the sandstones become more or less argillaceous and are interbedded with gray or greenish shales that, as a rule, are less well exposed than the underlying massive sandstone or quartzite. The Flathead quartzite in this area is approximately 250 feet thick and is of Middle Cambrian age. Exposures of similar beds have been observed by the writer in western Wyoming, in the Teton, Gros Ventre, and Wind River mountains, in the Hailey anticline, in Sweetwater Valley, in the Green Mountains, and in the Rawlins dome, and in northern Utah on the north flank of the Uinta Mountains.

GROS VENTRE FORMATION.

Conformably overlying the Flathead quartzite and grading down into the green-brown shales at the top of that formation is the Gros Ventre formation. This formation is approximately 800 feet thick and comprises green and brown clay shales, gray calcareous shales, thin beds of gray limestone, and flat-pebble limestone conglomerate. Good exposures of these beds are rare, because the soft shale erodes readily and the beds are generally concealed by soil and vegetation. However, excellent exposures may be observed in some of the deeper valleys or steep slopes where erosion is actively going on at the present time. The name Gros Ventre formation as here used was first proposed by Blackwelder, in 1912, in connection with the preparation of a report, not yet published, on the stratigraphy of the Wind River Mountains, in Wyoming. The name was chosen by Blackwelder from exposures of the beds in the eastern part of the Gros Ventre Range, at the head of Gros Ventre River. The same formation was traced by him into the Teton Mountains, which lie in the eastern part of the area treated in this report. The formation as described by Blackwelder has been identified by the writer in the Teton, Gros Ventre, and Wind River mountains of Wyoming, and he has observed beds of similar lithology and stratigraphic position in the Green Mountains, in Sweetwater Valley, in the Hailey anticline southeast of Lander, Wyo., and in northern Utah, on the north flank of the Uinta Mountains. In all these localities the beds overlie a

red quartzite formation. The Gros Ventre formation is believed to be of Middle Cambrian age.

GALLATIN LIMESTONE.

Conformably overlying the Gros Ventre formation is the Gallatin limestone, of Upper Cambrian age. This formation consists of limestone, shale, and sandstone, the limestone greatly predominating. The lower part of the formation is composed of finely crystalline limestone of dark yellowish-gray color, clouded with brown, so that it has on weathering a brownish-yellow appearance. Overlying this limestone are thin beds of gray calcareous sandstone, shale, and limestone which consist more and more of relatively thin-bedded limestone near the top of the formation. The uppermost beds contain little or no shale and are more or less siliceous. As a whole the formation, which is approximately 200 feet thick, is primarily one of limestone in which the rocks are more or less siliceous and contain thin beds or nodules of chert.

Outcrops of deposits of similar lithology and stratigraphic position have been observed by the writer at many places in Wyoming—in the Teton, Gros Ventre, Wind River, and Green mountains, in Sweetwater Valley, in the Hailey anticline southeast of Lander, and in Labarge Ridge, 40 miles northeast of Kemmerer—and also extend northward into Idaho and Montana and eastward into the Big Horn Mountains.

ORDOVICIAN SYSTEM.

BIGHORN DOLOMITE.

Unconformably overlying the Cambrian sediments is the Bighorn dolomite, of Ordovician age. Exposures of this formation are seen in the Teton Mountains and at several places in the Snake River Range and in the Bighole Mountains in eastern Idaho. The distribution of the formation was not determined, and only a preliminary examination was made. The formation consists chiefly of massive dolomite of a cream to light-buff color, somewhat darker when weathered, but on freshly broken surfaces appearing mottled with dark-gray cloudy patterns. In places the beds contain a little chert in irregular horizontal lenses and masses. This siliceous material on weathering forms on the surface a ragged network, which is characteristic of the formation. In part this deeply pitted surface may be due to the difference in porosity of the rock and the manner in which some of the particles are cemented. In this area the formation is approximately 350 feet thick, but apparently it thins toward the southeast.

Exposures of the Bighorn dolomite have been observed by the writer in the Snake River and Bighole mountains in Idaho and in the Teton, Salt River, Gros Ventre, Wind River, and Green mountains and in the Hailey dome southeast of Lander, in Wyoming.

SILURIAN SYSTEM.

Unconformably overlying the Bighorn dolomite along the west flank of the Teton Mountains is a thin-bedded dense, brittle white slabby dolomite which is both distinctive and persistent. The individual beds range in thickness from 1 to 12 inches and show remarkable wavy stratification lines. On weathering some of this dolomite becomes as smooth as porcelain and shows on the surface numerous shallow depressions in rectangular pattern. Eliot Blackwelder, who has recently studied the Paleozoic formations along the west flank of the Teton Mountains and determined their areal distribution, informs the writer that on Leigh Creek, on the west slope of the Teton Range, where he studied detailed sections of these beds, they aggregate about 50 feet in thickness, and are limited both above and below by unconformities. He has observed similar conditions at several places in the Wind River Mountains.

DEVONIAN SYSTEM.

THREEFORKS FORMATION AND JEFFERSON LIMESTONE.

Above the thin-bedded white dolomite of Silurian age and below the massive cliff-making ledges of the early Carboniferous (Mississippian) Madison limestone occurs a much less resistant group of black, green-gray, and brown shales interbedded with dark fetid sandstones and limestones, which in the Teton Mountains are approximately 350 feet thick. No measurement of their thickness was made in the Bighole Mountains, but it is believed that in this general region they range in thickness from 350 to 400 feet. The lower 100 to 150 feet of beds are barren of fossils and consist of relatively massive crystalline limestone, darker than the overlying rocks. The upper part of the series contains more shale and thin-bedded limestone, which as a rule are much lighter in color and in which fossils are frequently found, but the fossils are not conclusive enough to determine whether the beds belong to the Upper, Middle or Lower Devonian. The lithologic character of these beds, however, and their position in the stratigraphic section indicate that they closely resemble the Jefferson and Threeforks formations of the Yellowstone National Park.¹ Although the beds in this area have not been separated into two formations, it is highly probable that the lower dark crystalline limestone or shale that gives the strong fetid odor represents the Jefferson limestone and the overlying 200 feet of strata represents the Threeforks formation of the Park region.

Exposures of similar rocks were observed by the writer in 1906, while making a study of the coal beds in the vicinity of Labarge

¹ U. S. Geol. Survey Geol. Atlas, Yellowstone National Park folio (No. 30), 1896; Geology of the Yellowstone National Park: U. S. Geol. Survey Mon. 32, pt. 2, 1899.

Ridge, in T. 26 N., R. 113 W. sixth principal meridian, Wyo., about 40 miles northeast of Kemmerer. In 1907 E. M. Kindle measured a section across the beds near the south end of Labarge Ridge and found that the Devonian in this locality is at least 1,080 feet thick. Regarding these beds, Kindle makes the following statement:¹

In this section the gray and black limestone is preceded by beds holding a Cambrian fauna and followed by a limestone holding the usual Madison limestone fauna. The 80-foot shale formation at the top of the magnesian limestone appears to occupy the position of the Threeforks shale, but it is barren of fossils. Composition, texture, manner of weathering, and relationship to the other parts of the section all indicate the magnesian limestone to be the same as the Jefferson limestone of the Montana sections.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

MADISON LIMESTONE (LOWER MISSISSIPPIAN).

The basal Carboniferous rocks are dark bluish-gray, relatively thin-bedded cliff-making limestones, in places consisting of massive gray-blue limestones with numerous beds of dolomite and a few thin beds of shale. The entire series is approximately 1,000 feet thick. The fauna collected from these marine beds at many horizons include many cup corals, *Syringopora*, *Loxonema*, *Productella*, *Spirifer centronatus*, *Chonetes*, *Euomphalus*, etc., and according to G. H. Girty corresponds to the fauna of the basal portion of the "Wasatch limestone," of the Wasatch Mountains of Utah, as described by earlier writers.

BRAZER LIMESTONE (UPPER MISSISSIPPIAN).

Above the Madison limestone, apparently in conformable succession, occurs a series of massive light to dark gray limestones, weathering white to light gray, which represent the Brazer limestone of northern Utah and southeastern Idaho. The total series of beds at the south end of the area examined in this reconnaissance survey are approximately 1,000 feet thick, but in the northeastern part, in the Teton Mountains, they are only about 200 feet thick. Locally there is near the top a zone of dark shale about 15 feet thick. In places also the beds contain chert nodules in concentric and irregular forms and streaks of chert. The limestones are here and there specked with siderite and seamed with calcite or aragonite and at some horizons are abundantly fossiliferous. The fauna includes large cup corals with many fine septa, *Syringopora*, *Lithostrotion*, *Martinia*, and *Productus giganteus*.

¹ U. S. Geol. Survey Bull. 543, p. 37, 1914.

PENNSYLVANIAN SERIES.

WELLS FORMATION.

The Brazer limestone is succeeded by a series of sandy limestones, calcareous sandstones, and quartzites of somewhat variable character, which represent the Wells formation of southeastern Idaho. At the type locality in Wells Canyon, in T. 10 S., R. 45 E., the formation consists of three portions having a total thickness of about 2,400 feet. Toward the north the thickness greatly decreases and a change in the lithology can be observed. The total series of beds at the south end of the area examined in the reconnaissance survey is approximately 1,000 feet thick; at the north end of the area they are only about 300 feet thick.

In the type locality¹ the upper and lower portions of the Wells formation are predominantly calcareous. The middle is mainly sandy. The upper limestone, 75 feet thick, consists of dense gray siliceous limestone or calcareous sandstone which weathers into white massive beds that are topographically conspicuous as cliff makers. Bluish-white chert occurs in bands 2 inches to 1 foot thick and locally in ovoid nodules. Toward the base the chert becomes more nodular and darker. Silicified fragments of brachiopods project in little crescents from the weathered surface of the limestone. The most abundant fossils are *Squamularia* and a large *Productus*. The middle portion comprises 1,700 to 1,800 feet of calcareous sandstone and quartzite, with a few thin beds of limestone, weathering white, red, or yellow and forming smooth slopes with few projecting ledges. No fossils have been found in this member. The lower portion is from 100 to 800 feet thick. The rocks are cherty limestones and interbedded sandstones and form prominent cliffs. They weather gray or reddish. The base of the formation is marked by a *Schizophoria* zone, containing also *Marginifera*, *Composita*, *Spirifer rocky-montanus*, Bryozoa, etc.

LATE CARBONIFEROUS (PERMIAN SERIES) TO RECENT.

FORMATIONS INCLUDED.

For convenience in mapping and because of lack of information in many parts of the area all the beds overlying the Wells formation and underlying the Quaternary deposits in this area have been grouped together. These rocks, which correspond to the Laramie and in part to the Jura-Trias of the Hayden Survey reports on this area, comprise the Phosphoria formation (Permian), the Woodside formation, Thaynes limestone, and Ankareh shale (all Triassic), the Nugget sandstone, Twin Creek limestone, and Beckwith formation

¹ Richards, R. W., and Mansfield, G. R., The Bannock overthrust: Jour. Geology, vol. 20, pp. 681-700, 1912.

(all Jurassic), the Bear River and Aspen formations and the overlying coal-bearing sandstones and shales of the Frontier formation (all Upper Cretaceous), and the unconformably overlying undifferentiated Tertiary deposits. As most of these formations occur at a considerable distance stratigraphically above the phosphate horizon very little study was made of their distribution.

CARBONIFEROUS SYSTEM.

PERMIAN SERIES.

PHOSPHORIA FORMATION.

The Phosphoria formation, of Permian age, overlies the Wells formation conformably, so far as observed in the course of this and earlier examinations. Its stratigraphic relation to the overlying and underlying formations in the Snake River Range is shown in the traverse sections along Pine, Rainy, and Indian creeks (figs. 2, 3, and 5). The Phosphoria formation carries the economically valuable deposits of phosphate of this and the surrounding region, and in this area the entire formation ranges in thickness from 75 to 400 feet.

In the Preuss Range of Idaho, southwest of the area covered by this reconnaissance, the formation has been examined in detail and found to consist of two parts. The upper part is mainly chert and cherty limestone, and has been called the Rex chert member. This member ranges from a maximum thickness of about 450 feet to a feather-edge but usually is from 50 to 200 feet thick. The basal portion of the formation consists of 75 to 630 feet of alternating brownish shales, brownish sandstone, compact fetid limestones, usually lenticular, with one, two, or three zones bearing high-grade oolitic phosphate rock which contains 70 per cent or more of tricalcium phosphate and occurs in beds from 1 to 7 feet thick.

Within the area examined the natural exposures are for the most part not good enough to afford detailed sections. In all the districts where the outcrop is indicated on the map the formation was noted as composed of ledge-making cherts at the top (Rex chert member) and softer rocks—shales and sandstones, with phosphate rock—at the base. The upper portion locally, as on Pritchard Creek south of Snake River, near the north end of the Caribou Mountains, includes a thin bed of high-grade rock phosphate. At a few localities, as on Snake River and at the south end of the Blackfoot Range, a thin bed of phosphate was found overlying the Rex chert, but in no place is this bed known to be of commercial value. It is thought that careful measurements may show that the upper chert portion of the formation (Rex chert member) occupies a relatively greater part of the entire section in this area than it does farther south, but that the entire series thins toward the north. The areal distribution of this forma-

tion, so far as known, is practically represented by the line indicating phosphate outcrop on Plate I. Most of the area shown on the map without a geologic pattern is underlain by phosphate deposits, but more detailed work is required before the depth and attitude of the beds in that area can be determined.

TRIASSIC SYSTEM.

Triassic rocks, including the Woodside, Thaynes, and Ankareh formations, occur throughout western Wyoming and eastern Idaho. Exposures of these rocks have been examined in western Wyoming along the Meridian and Absaroka ranges, on Thompson Plateau, and in the Sublette, Salt River, and Wyoming mountains. In eastern Idaho they have been studied in the Bear River, Preuss, Blackfoot, Caribou, Snake River, and Bighole mountains. In all of this area these beds were for the most part mapped by the Hayden Survey as Jura-Trias but also in part as Carboniferous.

WOODSIDE FORMATION.

The Woodside formation conformably overlies the Permian Phosphoria formation and is composed mainly of russet-brown to olive-green calcareous shales, intercalated with muddy limestone lentils in which fossil shells are so closely matted that their specific characters are often barely discernible. The formation in this area is from 800 to 1,000 feet thick. Toward the top the limestones become a prominent feature of the formation, and throughout much of eastern Idaho the distinction between these and the overlying Thaynes limestone depends mainly upon the recognition of a cephalopod zone containing *Meekoceras* at the base of the Thaynes.

THAYNES LIMESTONE.

The Thaynes limestone, which apparently lies conformably upon the Woodside formation, includes both thick-bedded and thin-bedded, platy limestone and has a total thickness of 700 to 1,000 feet. The rock has a bluish-gray color on fresh fracture but weathers to light brown or buff and generally to an uneven sandy surface. The geologists of the Hayden Survey noted the *Meekoceras* zone at several places in the southeastern part of Idaho, in the Preuss and Blackfoot mountains, and mapped it in the Salt River Range and in the Wyoming Range as far north as Virginia Peak. This zone was not observed north of Snake River, but very probably detailed work will prove that it occurs in the Snake River and Bighole mountains.

ANKAREH SHALE.

A red series ranging in thickness from 200 to 500 feet and composed of red shale and intercalated mottled sandstone unconformably overlies the Thaynes limestone and is known as the Ankareh shale. This formation and the two immediately underlying formations were originally described by Boutwell from observations in the Park City mining district, Utah. The similarity of the beds in the Idaho-Wyoming section to those around Park City has led to the use of the same formation names in this region. Red shales which are representative of the Ankareh shale were noted in the canyons of Pritchard and Fall creeks in the Caribou Mountains, in the Salt River and Wyoming ranges south of Snake River, and along the east side of the Snake River Range, the west side of the Bighole Mountains, and the southwest side of the Teton Mountains north of Snake River.

JURASSIC SYSTEM.

NUGGET SANDSTONE.

The Nugget sandstone overlies the Ankareh shale conformably and consists of massive red sandstone with white conglomeratic sandstone in places at the base and top of the formation. Locally the sandstone is silicified to a quartzite. Owing to its massive and resistant character the Nugget sandstone forms high ridges with broad rounded slopes. The formation thins toward the north, and in the north end of the Caribou Range south of Snake River is approximately 1,000 feet thick. The thickness of the Nugget sandstone was not measured north of Snake River in either the Bighole or the Snake River mountains, but the formation was recognized throughout the area examined in 1911 and 1912 along Fall Creek and Pritchard Creek, in the Caribou Range, and at several places in the Snake River, Bighole, Teton, Wyoming, and Salt River ranges. The formation thins toward the north, and its thickness is believed to range from 1,000 feet near the south end of the area to approximately 500 feet at the north end.

No fossils were found in the formation in this area, but Jurassic fossils were obtained by Gale from corresponding beds in northwestern Colorado, and the formation is therefore now classified as Jurassic.

TWIN CREEK LIMESTONE.

The Twin Creek limestone overlies the Nugget sandstone, and, so far as observed in the course of this examination, is conformable to it. The beds consist principally of grayish-white shaly limestones and are readily recognized wherever they are exposed. The Twin Creek becomes thinner toward the north and is approximately 1,200 feet thick on Fall Creek, in the northern part of the Caribou Range, and

800 feet at the north end of the area examined. The beds in this formation are exposed in this area on Bailey Creek and Little Greys River in Wyoming and in the Snake River and Bighole mountains in Idaho. On Rainy Creek in the Snake River Range, 450 feet of beds were measured below the Beckwith-Twin Creek contact without seeing the base of the formation. In some areas in Idaho and Wyoming these beds were for the most part mapped by the geologists of the Hayden Survey as a portion of their Laramie. They have been traced by the writer from the southwest corner of Wyoming northward to Snake River and have been examined at many places in eastern Idaho south of Snake River, but were noted north of Snake River in this examination only on Rainy Creek and at several places between the Darby and Absaroka faults, and on the northeast flank of the Bighole mountains in the vicinity of Horseshoe Creek. Their occurrence at these localities clearly indicates that the Twin Creek limestone is exposed at a number of places in the Snake River and Bighole mountains. The fauna includes *Pentacrinus asteriscus*, *Camptonectes pertenuistriatus*, *Trigonia americana*, *Astarte meeki*, *Thracia weedi*, *Gryphaea calceola*, *Ostrea*, *Pholadomya*, and *Pleuromya*.

BECKWITH FORMATION.

The Beckwith formation overlies the Twin Creek limestone and is extensively exposed in the northeastern part of the Bighole Mountains and in the area east of the main crest of the Snake River Range, or between the Darby and Absaroka faults. The exposures of these beds and their relations to one another are indicated in the sections along Pine and Rainy creeks (figs. 2 and 3, pp. 42, 43). Beds of Beckwith age have been examined and mapped by the writer in the Salt River, Snake River, and Wyoming mountains in western Wyoming and in the Snake River, Preuss, Caribou, and Blackfoot mountains in eastern Idaho. In all these localities the beds were mapped by the geologists of the Hayden Survey as part of their Laramie formation. The Beckwith formation consists of reddish or chocolate-colored sandstone and shale, associated with whitish to grayish limestone and red conglomerates, and in this general region ranges in thickness from 900 to 4,000 feet. The upper member consists of calcareous sandstone, red conglomerate, and massive gray limestone. In 1906 the writer collected fossils from these beds on Hoback River, on Meridian Ridge, and at numerous other localities in the Hoback Range in western Wyoming.¹

¹ Schultz, A. R., Geology and geography of a portion of Lincoln County, Wyo.: U. S. Geol. Survey Bull. 543, pp. 53-54, 1914. Mansfield, G. R., and Roundy, P. V., Revision of the Beckwith and Bear River formations of southeastern Idaho: U. S. Geol. Survey Prof. Paper 98, pp. 70-84, 1916.

CRETACEOUS SYSTEM.

UPPER CRETACEOUS SERIES.

BEAR RIVER FORMATION.

Overlying the Beckwith formation occurs a series of beds whose thickness in this area was not determined but is believed to be approximately 800 feet. They consist of gray limestones, calcareous sandstones, dark-colored shales, thin and impure coal beds, brownish and gray sandstone, and light calcareous deposits. The beds are very widely distributed south of Snake River, north of the old Lander trail, and east of Willow Creek, lying for the most part on the west flank of the Caribou Range or between that range and Willow Creek. Beds of the same type and of the same age occur in Wyoming between the Salt River and Wyoming mountains, forming part of the crest of the Greys Ridge anticline. Good exposures were observed along Snake River east of the Salt River and Snake River ranges and also east of the Wyoming Mountains near the mouth of Hoback River. Similar beds were noted at many places along the strike of the beds north of Snake River, in the area between the Darby and Absaroka faults. The formation is coal bearing in many places, but the coal beds are too thin and impure to be of commercial value, although they may serve locally as a source of coal for domestic use.

The beds of the Bear River formation throughout most of the field have the same dip and strike as the underlying formations and may therefore readily pass as a conformable series. It is known, however, by the absence of the Lower Cretaceous, that an unconformity of considerable magnitude exists between the Bear River formation and the underlying Beckwith formation.

The fauna collected from the Bear River formation in the vicinity of Snake River includes *Pyrgulifera humerosa*, *Campeloma macrospira*, *Corbula pyriformis*, *Corbicula durkeei*, *Unio*, *Viviparus*, and *Goniobasis*. In the fall of 1912 E. G. Woodruff collected a small lot of Cretaceous fossils on Pine Creek in sec. 19, T. 3 N., R. 45 E., in the Bighole Mountains, about 5 miles southwest of Victor, Idaho. Among these T. W. Stanton identified *Corbula pyriformis*, *Corbicula durkeei*, *Pyrgulifera humerosa*, and *Pachymelania* sp. In 1911 the writer made a hurried examination of similar beds in the Fall Creek basin, along the west flank of the Caribou Mountains, Idaho, at a locality 2 miles northeast of Herman post office, northeast of Grays Lake. About a quarter of a mile east of the east quarter corner of sec. 25, T. 3 S., R. 43 E., a few fragmentary fossils were collected from beds lithologically resembling the Bear River formation of western Wyoming. A similar fossil bed was seen where Fall Creek enters the canyon. It is more than likely that St. John and Peale, of the Hayden Survey, mapped these beds, together with a part of the Beckwith

and Twin Creek formations, as Laramie on the basis of similar fresh-water fossils. T. W. Stanton, who examined the fossils collected in T. 3 S., R. 43 E., reports on them as follows:

I have examined the small lot of fresh-water fossils which you recently handed me from a locality northeast of Grays Lake, on the westslope of the Caribou Range, about 2 miles east of Herman, Idaho. It has not been found practicable to develop the fossils by etching or otherwise, and the preservation of the specimens on weathered surfaces is not satisfactory. Fragments of *Unio* and casts of *Viviparus* or *Campeloma* are recognized, and *Goniobasis* and possibly other genera of fresh-water gastropods may be represented. In my opinion this fauna is Cretaceous, but on account of the absence of definitely characteristic forms I am unable to determine whether it belongs to the Bear River formation. Similar imperfect fossils have been collected in Montana in rocks that are provisionally referred to the Kootenai formation. Additional good collections and accurate stratigraphic data concerning the rocks that were mapped as Laramie by St. John in this general region are greatly desired.

ASPEN FORMATION.

The Aspen formation is composed of black shale, dark-drab to gray sandy shale, and gray sandstone. In places the sandy shale weathers into small splintery fragments and the harder sandstone layers produce long rounded hills of peculiar gray color. Outcrops of these beds were observed along the Wyoming Range in the area between the Absaroka and Darby faults and on the northeast flank of the Bighole Mountains in the vicinity of Horseshoe and Packsaddle creeks. No carefully measured section of these beds was made in any of these localities, but the total thickness approximates 1,000 feet. Beds in this formation yield oil in southwestern Wyoming, and throughout the area examined in a previous survey contain abundant fish scales, but only a few good collections of fossils were obtained from the beds.

FRONTIER FORMATION.

Conformably overlying the Aspen formation occurs a series of sandstone, clay, shale, and shaly sandstone beds with which are associated beds of carbonaceous shale and of coal, the entire series approximately 3,000 feet thick, which constitute the Frontier formation. The sandstone is grayish white and yellow and occurs both in thick massive beds and in thin shaly beds. The coal beds are not continuously exposed for any great distance, nor are the associated strata sufficiently characteristic to render correlation certain, but it is known that this formation is coal bearing throughout the region extending from southern Wyoming northward to the north end of the Bighole Mountains, southeast of St. Anthony, Idaho. Coal beds and other strata belonging to the Frontier formation were observed in the Wyoming Range at the mouth of Hoback River south of Jackson, Wyo.; in the Greys River area, in western Wyoming south of Snake River; in the Snake River and Bighole mountains north of

Snake River; in the area between the Absaroka and Darby faults; and on the northeast side of the Bighole Mountains in the vicinity of Horseshoe and Packsaddle creeks, where the beds are exposed on both sides of the overturned fold or faulted anticline. The fauna of the Frontier formation consists of *Ostrea glabra*, *Cardium*, *Mactra*, *Anomia*, *Inoceramus*, *Goniobasis*, *Turritella*, *Barbatia*, *Corbula*, *Gyrodes*, *Pholadomya*, *Avicula*, *Ostrea*, and *Glauconia*.

On Packsaddle Creek in the SW. $\frac{1}{4}$ sec. 24, T. 5 N., R. 43 E., occurs an outcrop of soft gray sandstone which dips 50° S. 55° W. and which has been quarried for the purpose of building a dam at the reservoir in secs. 18 and 19, T. 5 N., R. 44 E. In this sandstone the writer found fragments and several complete casts of *Inoceramus labiatus*, *Inoceramus erectus*, and other associated fossils of the Frontier formation which indicate that these beds and their associated coals are of Colorado age.

Woodruff in the fall of 1912, while examining the coals in this vicinity, collected a small lot of Cretaceous fossils in the NW. $\frac{1}{4}$ sec. 6, T. 4 N., R. 44 E., and at the Brown Bear mine, in the SE. $\frac{1}{4}$ sec. 25, T. 5 N., R. 43 E., of which T. W. Stanton identified the following:

NW. $\frac{1}{4}$ sec. 6, T. 4 N., R. 44 E.:

Modiola sp.
Cardium sp.
Corbicula? sp.
Corbula undifera Meek.
Neratina.

SE. $\frac{1}{4}$ sec. 25, T. 5 N., R. 43 E.:

Cardium sp.
Lucina? sp.
Corbula sp.
 Undetermined material.
 Shells.

These fossils suggest the Mesaverde formation of the Rock Springs field, but they are not distinctive enough to warrant positive identification of the horizon. There are some similar forms also in the Adaville formation in western Wyoming.

HILLIARD AND ADAVILLE FORMATIONS (?).

The beds immediately overlying the Frontier formation in southwestern Wyoming constitute the Hilliard formation, which consists of dark-colored sandy shale, clay, and shaly sandstone, chiefly of Colorado age but in part of Montana age. The entire series is soft and weathers readily, forming marked depressions in which comparatively few exposures are seen. In southwestern Wyoming the Hilliard formation is overlain by the coal-bearing Adaville formation, also of Montana age. Beds belonging to the Hilliard and Adaville formations were not observed in this area in the course of the reconnaissance examination. This portion of the Upper Cretaceous series may, however, be present in some parts of the Snake River or Bighole mountains, but the examinations thus far made indicate that all the Cretaceous beds exposed at the surface are older than the

Adaville and Hilliard formations. Until the area is studied in detail it will not be possible to state definitely whether or not beds belonging to these formations occur in surface exposures in the Snake River and Bighole mountains or whether they are present in any part of the field beneath the lava-covered plains of the Teton Basin.

CRETACEOUS OR TERTIARY SYSTEM.

EVANSTON FORMATION (?).

The deposition of the Adaville formation in southwestern Wyoming was succeeded by a long period of folding, faulting, and erosion, after which was laid down a series of gray, yellow, and black carbonaceous shales, clay, and white and yellow sandstone, which make up the Evanston formation. It is not positively known whether or not this formation,¹ which carries coal in the Hoback River basin and in the vicinity of Evanston, Wyo., is present in the area covered by this report. Beds resembling the Evanston formation, however, occur on the east side of Snake River south of Jackson, Wyo., where coal-bearing beds lie apparently conformably below the Almy formation.

TERTIARY SYSTEM.

Eocene Series (Wasatch Group).

Almy Formation.

The Almy formation, which may be equivalent to the Pinyon conglomerate of the Yellowstone Park region, is well exposed between Snake and Hoback rivers in Tps. 39 and 40 N., R. 116 W., Wyoming, where, in beautiful weathered exposures, conglomerate representing this formation may be traced from Hoback River northwestward to Snake River. The beds here strike N. 32° W. and dip about 25° NE. At no other place in the area examined were these deposits observed. The conglomerate is overlain by later Tertiary deposits.

Knight Formation.

Beds belonging to the Knight formation were identified southeast of Cheney post office, on the east side of Snake River, overlying the Almy formation. They consist of red and yellow sandy clays, shales, sandstones, and concretionary limestones and extend eastward south of the Gros Ventre Mountains, connecting with the beds observed north and east of the Hoback River basin.

¹ Veatch, A. C., U. S. Geol. Survey Prof. Paper 56, pp. 76-87, 1907. Schultz, A. R., U. S. Geol. Survey Bull. 543, pp. 68-71, 1914.

PLIOCENE (1) SERIES.

At Snake River in T. 1 S., R. 45 E., about 3 miles southeast of the mouth of Bear Creek, is a small area of calcareous conglomerates and inferior lithographic limestone which were provisionally mapped as Carboniferous by St. John, but which appear in the light of recent detailed study in Idaho farther to the south to be Tertiary lake beds, probably of Pliocene age. This correlation is made purely on lithologic and structural grounds. Similar conglomerates were observed along the west flank of the Snake River Range at several places along Snake River between Alpine and Irwin, and on Indian and Elk creeks.

QUATERNARY SYSTEM.

GLACIAL DEPOSITS.

Glacial deposits consisting of old eroded drift were observed on the slopes of the Teton, Bighole, and Snake River mountains, and fresh moraines were seen in some of the mountain valleys. In some of the smaller valleys near the summits of the higher peaks remnants of the receding mountain glaciers were seen, which earlier in the summer had extended much farther down the valley. In one place north of the canyon of the Snake one of these small valley glaciers had extended during the previous year nearly to the mouth of the valley, where it joins Snake River, and the moraine left by the melting ice could be distinctly seen through the entire distance, approximately half a mile.

SPRING DEPOSITS.

In certain parts of the area described in this report, notably along Snake River and Fall Creek, occur deposits of travertine and numerous hot springs, many of which are depositing tufa at the present time. These hot springs may represent the southwestern extension of conditions similar to those that gave rise to the numerous renowned hot springs in the region of the Yellowstone National Park. F. H. Bradley,¹ of the Hayden Survey, visited some of these springs in 1872 and gave an excellent account of the springs and their deposits. Regarding the hot springs of Snake River, which occur along the Darby fault in T. 39 N., R. 116 W., Wyoming, he makes the following statement:

A small cluster of these [Warm Springs] escape among the gravel on the edge of the river in the south side, emitting an abundance of sulphureted hydrogen. Though somewhat mixed with the river water, they gave a temperature of 117°. About a hundred yards below this a group of calcareous springs has built up a dam of tuff so as to flood several acres about the vents, which are now inaccessible. The general flow from the pool gave a temperature of 94°.

¹ U. S. Geol. Survey Terr. Sixth Ann. Rept., p. 269, 1873.

The writer visited this locality in 1906 and found the condition of the springs much the same as in 1872, at the time of Bradley's visit. He observed, however, other hot springs not described by Bradley. Some of these lie on the gravel bench on the south side of Snake River. Over one of the larger of these springs a bath-house has been erected. A number of other springs occur in this locality on the gravel terrace near Counts's ranch.

On the lower part of Snake River both spring deposits and hot springs were observed at several places from Alpine to Heise, Idaho. All the springs at Alpine, Blowout, and Heise, on Fall Creek, and in the lower Conant Valley, Idaho, occur along the fault line between the Caribou Range and the Snake River valley. It is very probable that similar deposits will be found at other localities in the mountains along this fault line as soon as a more detailed examination of this region is made. At Heise, on Snake River, in the SE. $\frac{1}{4}$ sec. 25, T. 4 N., R. 40 E., is the most northwestern hot spring observed in the course of the reconnaissance examination along this fault line. This spring is mentioned by Bradley,¹ who says:

Some 3 or 4 miles below the mouth of this last canyon [lower Snake River canyon] a small hot spring, 4 or 5 feet across, stands on the north bank of the river about 20 feet above the bottom. This was not visited by any of our party but was reported by our guide to be too hot for one to hold his hand in it for more than half a minute. White-spring deposits were seen from a distance at several points on the north bank, but there is believed to be no flow at these points at the present time.

About 18 miles southeast of this locality, at the lower end of Conant Valley, in T. 2 N., R. 43 E., occurs another hot-spring deposit on the south side of Snake River. Of these deposits Bradley says:

At the base of the mountain on the southwest side of the valley, just above the head of this lower canyon [lower Snake River canyon], calcareous deposits from now extinct springs form a heavy mass reaching about 100 feet up the mountain side.

In sec. 29, T. 1 N., R. 43 E., on Fall Creek, immediately west of the fault along the east side of the Caribou Range, where the crest of the anticline in the Paleozoic beds crosses the creek, occur numerous warm springs. Some of these are on the south side of the creek and several in the bottom of the stream. The largest one, which supplies a stream that fills an 8-inch pipe, comes in on the north side of the creek right at the water's edge. The water from most of these springs is luke warm and carries hydrogen sulphide. Considerable sulphur is deposited around the springs and in the stream. The stones and ground are coated with greenish-yellow algae. Travertine and other spring deposits are built up around the springs, the rims and domes of which are several feet in height.

¹ Bradley, F. H., *op. cit.*, p. 271.

The largest spring deposits and the hottest water observed along the fault between the Snake River valley and the Caribou Mountains occurs on Snake River southwest of Blowout, in secs. 13 and 24, T. 2 S., R. 45 E., and in the southwest quarter of T. 2 S., R. 46 E. One of these springs on the east bank of Snake River is now utilized for a bathhouse. Regarding this group of springs Bradley,¹ who visited them in 1872, makes the following excellent statement:

Here also is located a cluster of warm springs, making calcareous, sulphurous, and saline deposits. The largest spring, the Washtub, has built up a flaring table, 1 foot high, of an oval form, measuring about $4\frac{1}{2}$ by $7\frac{1}{2}$ feet, upon a mound consisting of calcareous mud, scarcely solidified, of from 5 to 7 feet above the creek bottom in which it stands. The central table has contracted so as to crack across diagonally, and the flow now escapes at its western base, depositing a fine mud tinged in the full pools with a faint sulphur-yellow, but pure white in the dry ones. These pools cover the mound in descending steps of great beauty. The present flow is southward, though it has been on all sides in succession. The deposit on the surface of the mound is still very soft and showed at the time of our visit (Oct. 6) the tracks of a small bear, who had recently investigated the wonders of the mound, even setting his foot on the central table. One mound, no longer active, is 5 feet high, with a circular base of about 5 feet diameter and an oval summit of about 1 foot by 6 inches. Many small springs escape along the bank for a hundred yards or more. The deposits vary greatly in color. At some points the odors of sulphurous acid and of sulphureted hydrogen were quite noticeable. The older deposits have built up a bank 10 feet high along the base of the terrace, and the beavers have taken possession and have dammed up on it the waters of the cold springs which flow from the second terrace at short intervals along this plain. On the opposite shore two considerable springs have built up their deposits against the foot of the mountain, one of which appears to be nearly dead. The highest temperature observed here was 144° . The Washtub gave 142° , and others 142° , 140° , 90° , 88° , etc.

Similar springs occur on the bottom lands along the west side of Snake River and drain into the sloughs and low depressions on the gravel terrace bench.

ALLUVIUM AND TERRACE GRAVELS.

Along all the large streams in this region occur considerable deposits of washed soil and gravels of Quaternary age. Some of the gravels along Snake River and its tributaries are washed for gold. For the most part the alluvial bottoms are small and are confined to narrow strips along the streams or are cut out entirely where the stream has intrenched itself in the lava bed. The largest of the alluvial bottoms occur along the Salt River valley and around Jackson, Wyo., along Snake River above the canyon, and in places along Snake River below the canyon. In addition to the alluvial bottoms along the larger streams, gravel, sand, and silt deposits form large alluvial fans in the Teton Basin and Snake River valley and occupy narrow strips in the bottoms of the mountain valleys.

¹ Bradley, F. H., op. cit., p. 260.

IGNEOUS ROCKS.

SNAKE RIVER BASALT.

Nearly all the northwestern part of the area is covered by igneous rocks, which consist largely of a series of lava flows whose relation to one another has not been accurately determined. There appear, however, to be two fairly distinct types of rock, which belong to the series of successive lava flows grouped by Russell under the term Snake River lava. The older lavas are rhyolites that cover extensive areas; the later basalt is less widespread in its distribution and is the most recent extrusive flow that occurs along the lower depressions. The greater part of the igneous rock is dense and in cliffs shows the development of irregular columnar jointing, but minor scoriaceous and cellular facies are found, especially near the margins of the flows. The surface of the basalt has a comparatively fresh and recent appearance, and the soil cover is thin except where it has been augmented by alluvial agencies. The number of flows has not yet been worked out in detail. It is evident that there are several, because of the intercalation of scoriaceous and tuffaceous lentils. The exact geologic range of the flows has not been determined, but it appears that some at least belong to the Tertiary and are of Pliocene age, while others, from their relation to the deformed beds of probable Pliocene age, are Quaternary.

The older lavas consist primarily of a massive flow which is uniform in composition but varies considerably in physical appearance. These rocks range from a few feet to a thousand feet or more in thickness and extend well up on the flanks of the Caribou, Snake River, Teton, and Bighole mountains. At the north end of each of these ranges the lava lies at elevations as high as the main part of the range, and within a short distance it completely conceals the northward extension of the Paleozoic rocks of which the range is composed. In the Teton Basin and along Snake River southwest of the Snake River Range large bodies of more recent Snake River basalt overlie the older flows. The basalt sheets are from a few feet to 200 feet thick and consist of dark-gray to bluish-black more or less vesicular rock containing some crystals of feldspars and ferromagnesian minerals.

The Tertiary beds on the west flank of the Caribou Range are overlain by igneous rocks or basalts similar to those which occur in the canyons farther to the north and west. The greater portion of the igneous rocks represents part of the extensive lava flows of the Snake River Plains, which have been referred in southern Idaho mainly to the Tertiary by Russell and in the Yellowstone National Park region to the Neocene by Hague and Iddings. There are, however, within this general area a number of subordinate cones, many of which are broken and shattered and undoubtedly served as the outlets for the

later lavas that surround them. Some of these are of Pleistocene or Recent age, if the Tertiary beds are correctly determined as Pliocene.

STRUCTURE.

GENERAL FEATURES.

The geologic structure of the area examined is rather complex, and no attempt was made to decipher it in detail. The mapping of the phosphate beds on some of the streams in the area, however, permitted the structure of some of the larger units to be worked out with considerable accuracy. The main mountain ranges are more or less parallel and extend in a northwesterly direction across the area examined. The one farthest to the southwest south of Snake River is the Caribou Range. Northeast of the Caribou Range lie the Snake River and Salt River ranges, the former north and the latter south of Snake River and east of Salt River. Immediately to the northeast of these are the Bighole and Wyoming ranges, which in places lie so near to the Snake River Range as to be taken as a part of it. Northeast of these parallel mountain ranges, in the northeastern part of the area, lies a high range known as the Teton Mountains, which in western Wyoming extends in a northerly direction from Snake River to the Yellowstone National Park.

CARIBOU RANGE.

The Caribou Range, which forms the southern boundary of the area examined, has a very complex structure and consists of an anticlinorium, as indicated by the sections traversed by the writer¹ in the autumn of 1911, along Fall and Tincup creeks. A large thrust fault extends along the east flank of the Caribou Range and probably represents the northward continuation of the fault that lies for the most part in Snake and Salt River valleys, west of the Salt River Range. It is along this fault that the numerous hot springs referred to are located. Minor faulting was observed at several places in the Caribou Range, but no attempt was made to study the relation of these faults to one another.

SNAKE RIVER AND SALT RIVER RANGES.

The Snake River and Salt River ranges consist of a series of rugged peaks and hills that have a general northwesterly course, extending from western Wyoming to the great lava plains southeast of St. Anthony, Idaho. The ranges were formerly continuous but have been separated by Snake River, which has forced a narrow passage through them. The Snake River Range lies north of the canyon and the Salt River Range south of it. The ranges lie immediately east of

¹ Schultz, A. R., and Richards, R. W., U. S. Geol. Survey Bull. 530, figs. 33 and 34, 1913.

the broad valleys of Snake and Salt rivers, which separate them from the Caribou Mountains. The Snake River and Salt River ranges have a very complex structure and consist of parallel anticlines and synclines, which are in places overturned and closely folded and with which is associated considerable faulting. A large thrust fault extends along the east flank of the ranges and represents the northward continuation of the Absaroka fault.¹ This fault, in which the thrust has come from the west, approximately separates the Snake River and Salt River ranges from the Bighole and Wyoming ranges. As a result of this thrust rocks of Carboniferous age are brought in places into juxtaposition with rocks of Cretaceous (Colorado) age. A short distance west of and more or less parallel to the Absaroka fault is another fault, which marks approximately the western limit of the phosphate-bearing beds in the Snake River Range. All the phosphate exposures observed in this part of the range lie between these two faults. Minor faulting was observed at several places, but no attempt was made to work out the structure of the ranges completely or to study the relation of the faults to one another. The major faults above mentioned were observed along all the streams flowing west into Snake River along which traverses were made, and are therefore indicated on the map as continuous faults.

BIGHOLE MOUNTAINS AND WYOMING RANGE.

The Bighole Mountains and Wyoming Range lie immediately north and east of the Snake River and Salt River ranges, from which they are separated by the Absaroka fault and a low depression along the Greys River valley and the headwaters of Elk, Palisade, Pine, Moody, and Canyon creeks. These ranges also were once continuous and have been cut nearly at right angles by Snake River. The part of the old range north of Snake River is known as the Bighole Mountains, and the part south of the river as the Wyoming Range. The geology of the range is complex and as yet little known. The rocks are highly folded and are broken by large faults, the exact positions of which have for the most part not been determined. The large thrust fault that extends along the east side of these ranges was mapped by the writer in 1906 as far north as Snake River and represents the northwestern extension of the Darby fault.² Its position in the Bighole Mountains was determined only at two localities south of Victor, Idaho, in the vicinity of station 39 of the Hayden survey,³ and west of Driggs, Idaho, in the vicinity of station 42. The stratigraphic relation of the beds along the fault in these two localities, the general trend of the mountain range, and the numerous large springs that lie

¹ U. S. Geol. Survey Prof. Paper 56, p. 109, 1907; U. S. Geol. Survey Bull. 543, p. 87, 1914.

² U. S. Geol. Survey Bull. 543, p. 84, 1914.

³ Station numbers correspond to those used in St. John's report and are shown on the map (Pl. I).

along the fault line on the east flank of the mountains between stations 39 and 42 indicate that the fault here observed is probably the northward extension of the Darby fault, which lies along the east flank of the Wyoming Range. The stratigraphic relations of the beds along the east and west sides of the Darby fault are similar to those along the Absaroka fault; in places Carboniferous or older rocks on the west are brought into juxtaposition with Cretaceous (Colorado) rocks on the east.

TETON MOUNTAINS.

The Teton Mountains form one of the most imposing ranges in the Rocky Mountain region. They appear to be a large fault block upon which the little-disturbed Paleozoic rocks dip gently toward the west. The main part of the range rises with a singularly abrupt slope from the west side of Jackson Hole, which marks the approximate location of the fault along the east side of the range. It culminates in the rugged Grand Teton, the third highest peak in Wyoming, reaching an altitude of 13,747 feet. The main part of the range extends about due north and consists of a gentle westward-dipping monocline crossed at the north by a low anticline which trends northwest. Near the south end of the range the beds are somewhat folded and the main ridge is crossed by a low anticline, whose axis trends northwest, lies immediately north of station 43 of the Hayden Survey, and in its northwestward extension nearly parallels the Bighole Mountains. The low pass south of station 43 separates the Teton Mountains from the Bighole and Wyoming ranges and affords the only wagon road at the south end of the range from Teton Basin, Idaho, into Jackson Hole, Wyo. The rocks along the east slope of the range consist largely of granite, gneisses, and schists. On the west slope of the range the Paleozoic beds overlie the pre-Cambrian rocks and slope off more gently to the broad Teton Basin, which lies between the Teton and Bighole mountains. The broad open plain of the Teton Basin is floored with nearly horizontal Tertiary or later sediments. The outcrops of the Mesozoic rocks are buried by extensive lava flows, which are in turn partly concealed by the alluvium in the bottoms of the basins and by widespread moraines on the plateau farther north.

MINERAL DEPOSITS.

PHOSPHATE.

GENERAL FEATURES.

Rock-phosphate deposits of the same type as those in eastern Idaho in the vicinity of Montpelier, south of Snake River, were found by the writer in September, 1912, while engaged in a geologic reconnaissance

examination north of Snake River in the vicinity of the Snake River and Bighole mountains. It is believed that commercial deposits of phosphate have not heretofore been generally known in this part of Idaho, and no sign was observed that these beds had ever been prospected for phosphate, although in a few places they have been prospected for coal.

The rock was found as float along the outcrop of the phosphate bed and in place along the central part of the Snake River Range, and was recognized by its physical characteristics. The more massive part of the bed, which is usually found as float, somewhat resembles a dark coarse granular limestone that may be mistaken on casual examination for a dark fine-grained basalt. It has an oolitic structure, is dark gray to black, is noticeably heavy in comparison with the sedimentary rocks with which it occurs, and on many of the weathered surfaces has a bluish-white coating. The oolitic structure, though constituting one of its most definite features, is in places somewhat obscure; in other places it is entirely missing and the bed may be composed entirely of shale-sandstone, or nonoolitic limestone, rich in phosphoric acid. By reason of the weaker constitution of the shaly rocks they commonly give way to weathering and decay at the surface, and the phosphate outcrop thereby becomes concealed wholly or in part, while the harder fragments of phosphate rock remain in the soil and are readily detected by one who is familiar with the appearance of the rock. In part of the area rock-phosphate float is but moderately abundant in the vicinity of the outcrops of the phosphate bed, but in other localities the surface is covered with numerous phosphate fragments.

The work done farther southeast in Idaho, where detailed examinations of the phosphate deposits have been made, and where sections of the phosphate shales, especially those immediately associated with the main phosphate bed have been measured and studied in detail, affords a good idea of the range of phosphate content which may be expected within the area covered by this report. Two of these sections, in Georgetown Canyon, T. 11 S., R. 44 E., and in T. 8 S., R. 44 E., Idaho, have been published.¹

A detailed section of the lower part of the Phosphoria formation was measured and sampled in 1909, exceptionally favorable conditions of exposure being found in the Georgetown district, in T. 11 S., R. 44 E. The section of the phosphate-bearing strata in Georgetown Canyon shows the largest amount of high-grade phosphate rock and probably the highest average phosphoric-acid content of all the sections that have been examined in detail in the western phosphate fields. It represents presumably the upper limit of

¹ U. S. Geol. Survey Bull. 530, pp. 278, 280, 1913.

conditions which may be found on prospecting within the area of this reconnaissance. The other section of the lower portion of the Phosphoria formation was measured and sampled about 26 miles north of Georgetown Canyon, in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 7, T. 8 S., R. 44 E. It shows the smallest amount of high-grade phosphate rock and also the lowest average content of phosphoric acid yet found in the sections measured in detail in the Idaho portion of the phosphate reserve, and will serve to illustrate the leanest conditions to be expected within the area of this reconnaissance.

DISTRIBUTION OF PHOSPHATE DEPOSITS BY STRUCTURAL DISTRICTS.

GENERAL CONDITIONS.

The distribution of the phosphate-bearing Phosphoria formation in the area examined can be inferred in part by examination of the accompanying map (Pl. I), on which the outcrops of the phosphate beds seen in the field are shown by lines with small crosses, and the inferred outcrops by light dash lines. The inferred positions in some parts of the field where the structure is complex and no examination of the phosphate beds was made are not indicated, although it is reasonably certain that the phosphate beds occur within well-defined limits, as along the east side of the Salt River and Snake River ranges, in the area between the Absaroka fault and the parallel fault to the west. The distribution of the Phosphoria formation also indicates in a general way the structure of the area. The phosphate beds in this area are very similar to those described by Gale, Richards, and Mansfield in their reports on the areas to the south. Only a few prospects have been opened on the phosphate beds in the area examined, and all of these were opened in search of coal. No attempt was made in the reconnaissance examination to prospect the phosphate outcrops, and therefore no detailed description of the beds can be given. Samples of float and fragments of rock in place picked up at several places show the presence of high-grade material and indicate that workable beds similar to those prospected farther south are undoubtedly present. A preliminary study of the phosphate rock was made and samples collected in some of the localities discussed below.

CARIBOU RANGE, IDAHO.

Phosphate rock of the same character as that in Georgetown Canyon, Idaho, was found in the Caribou Range at several places on Bear Creek, Indian Creek, Fall Creek, Pritchard Creek, and Garden Creek. One sample of rock obtained in Bear Creek yielded 28.93 per cent of phosphorus pentoxide (P_2O_5), or 63.36 per cent of tricalcium phosphate. No other analyses have been made of this rock. The general distribution of the phosphate deposits south of Snake River is

shown on Plate I. However, as many of the formations overlying the phosphate beds thin greatly toward the north, and as the numerous parallel anticlines in the Caribou Range expose rocks ranging in age from Beckwith to Nugget (see generalized section, p. 14), it is very probable that detailed geologic and stratigraphic work will show that phosphate beds underlie at depths less than 5,000 feet much of the area in the Caribou Range south and west of the phosphate outcrops shown on Plate I. The general relations of the Phosphoria formation to the overlying and underlying beds in the Caribou Range are shown in the sections measured along Tincup Creek, Fall Creek, and Pritchard Creek.¹ The southeastward extension of the phosphate beds could not be traced, as the rocks are concealed beneath the gravel and alluvium along Snake and Salt rivers. It is probable, however, that the beds continue southeastward and connect with the phosphate beds observed in the vicinity of Afton Creek, on the west limb of an overturned anticline southwest of Virginia Peak, which may represent a part of the structural fold observed along the east side of the Caribou Range west of Snake River.

SHAKE RIVER AND SALT RIVER RANGES.

GENERAL DISTRIBUTION.

Deposits of phosphate rock were found at several places from the north end of the Snake River Range to the south end of the Salt River Range, but no attempt was made to trace the outcrop of the phosphate beds from one locality to another. Traverses were made across the Snake River Range along Pine, Rainy, Elk, and Indian creeks and along Snake River. Examinations were also made of the rock along some of the divides between these streams, particularly in the vicinity of Palisade Creek and north of Pine Creek. The general distribution and location of the phosphate deposits in this range are shown on Plate I and in greater detail on the traverse maps of areas along the streams (figs. 2 to 6). Most of the deposits lie along the east side of the range, in that part of the divide lying immediately west of the Absaroka fault. Although the beds have not been traced for any great distances beyond the localities where they were examined, it is reasonably safe to infer from what is known regarding the general structure of the range that the phosphate beds are more or less continuous from one locality to another. Owing to the complexity of detail in the structure of this part of the range, however, the outcrop of the phosphate bed is certain to be somewhat irregular, and even its approximate location can not be inferred until a more detailed examination of the entire region is made.

¹ U. S. Geol. Survey Bull. 530, figs. 33, 34, and 35, 1913.

PINE CREEK.

The lower part of Pine Creek lies on the Snake River basalt. About 2 miles up Pine Creek from the point where the stream crosses the west boundary of the Palisade National Forest rocks of Carboniferous age are exposed. The southwestern part of the range consists chiefly of Paleozoic limestones, in which numerous horn corals were observed. The beds along the west side of the range dip 20° to 50° W., but in the vicinity of the fault east of Flemming's ranch the dip ranges from 50° to 70° W. Some of the beds along this ridge appear to be older than the Madison limestone. This fault, in which the downthrow is on the east, brings the Woodside formation into contact with Paleozoic limestone on the west. Minor faulting was also observed in the hills north of Flemming's ranch, but the exact location of the faults was not determined. Farther up the stream, west of the forest rangers' station, is the overthrust fault, which is believed to be the northwesterly extension of the Absaroka fault. Along this fault line quartzite of Pennsylvanian age (Wells formation) is brought into contact with beds of Jurassic age (Beckwith formation) on the east. Between these two faults were noted the phosphate beds. The rocks in this belt are badly broken and distorted, and no attempt was made to trace the phosphate beds for any distance along their outcrop. It may be expected, however, that when these beds are mapped in detail the phosphate will be found at several places west of the Absaroka fault. Phosphate float was picked up near the middle of this belt, just east of a massive ledge of gray cherty limestone, but no phosphate rock was found in place at this locality. The general relation of the beds indicates that the phosphate should be present below the massive ledge. If the phosphate occurs in place here, there is a fault between it and the phosphate outcrop to the east. The phosphate outcrop west of the forest ranger's station rests upon a bed of white limestone, which in turn rests upon quartzite beds; both limestone and quartzite belong to the Wells formation. A sample of phosphate obtained north of the road, at locality J (see Pl. I), yielded 27.51 per cent phosphorus pentoxide (P_2O_5), or the equivalent of 60.1 per cent tricalcium phosphate ($Ca_3(PO_4)_2$). The entire Phosphoria formation here is approximately 375 to 400 feet thick and contains at least one bed of phosphate about 4 feet thick. The sample collected does not represent the richest phosphate layer but the entire part of the bed exposed. The general relations of the beds as observed along the line of traverse are shown in figure 2.

In the summer of 1910 Eliot Blackwelder examined the phosphate beds along Pine Creek and found that the phosphate series is exposed in the central part of the range in a band trending approximately

N. 50° W., parallel with the range itself. Regarding these deposits he makes the following statement:

Exposures of phosphate beds on Pine Creek are very poor, but it was possible to recognize a gray quartzite (Wells formation) overlain by gray limestone and about 75 feet of phosphatic shale. A sample of the shale gives on analysis 36.8 per cent tricalcium phosphate. The expected beds of rich oolitic phosphate rock were not found but may well be present, although concealed by wash, soil, and tuff at the point examined. The phosphatic shale is overlain by the fossiliferous limestone, and massive chert beds generally associated in this region with the phosphate beds. On the whole, the general constitution of the phosphatic series in the Pine Creek section

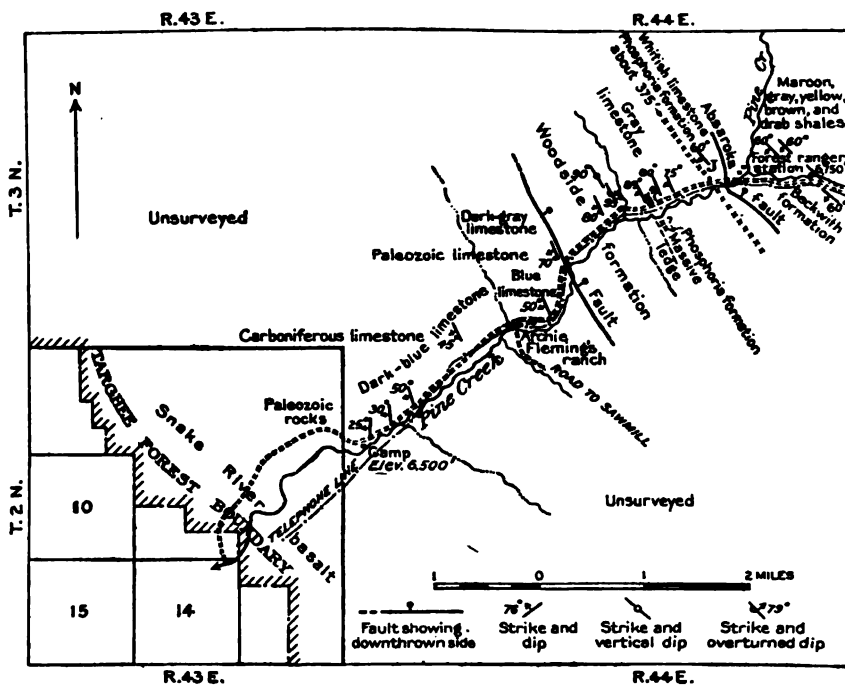


FIGURE 2.—Map showing traverse along Pine Creek, Tps. 2 and 3 N., Rs. 43 and 44 E., Idaho.

is so similar to that in the Preuss Range that it is safe to expect that phosphate deposits of notable value will be found in the Snake River Range when it is adequately explored.

RAINY CREEK.

The western part of the Snake River Range along Rainy Creek consists of rocks of the same kind as those observed on Pine Creek, for the most part of Paleozoic age. The range here is made up of several parallel folds, which are broken by faults. The anticline observed between Rainy and Palisade creeks forms the highest point of the Snake River Range at this place, and its axis passes through Baldy Mountain in a northwesterly direction, crossing the lower portion of Rainy Creek. The rocks exposed on the divide south of Rainy

Creek consists of Madison limestone and beds of Pennsylvanian (Wells) age. So far as known deposits of phosphate do not occur in this part of the range from Baldy Mountain east to the first fault shown on Plate I. If present they occupy the crests of the ridges and constitute remnants that have not yet been removed by erosion from some of the closely folded synclines.

The first prominent fault observed on going up Rainy Creek lies just east of the canyon on the south fork of the creek and may represent the southeasterly continuation of the westernmost fault observed on Pine Creek. The fault brings the Ankareh shale on the east into contact with the quartzite of the Wells formation on the west. The downthrow is on the east and is somewhat greater than on Pine Creek, although the general relations are the same. Farther up the stream

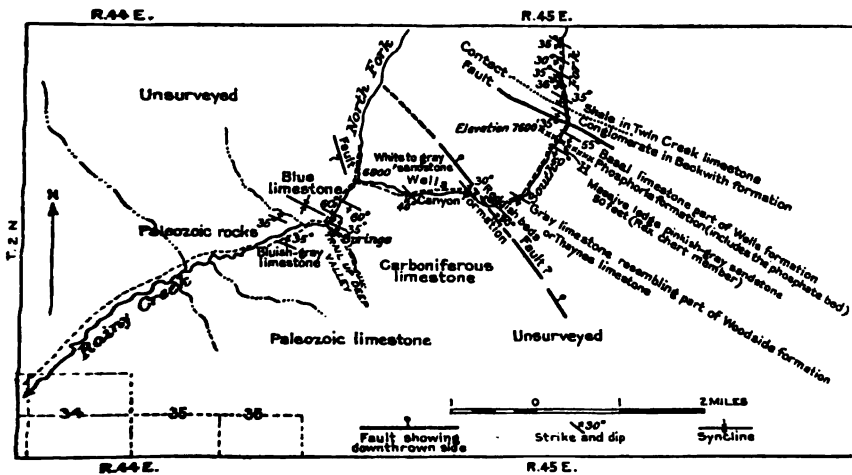


FIGURE 3.—Map showing traverse along Rainy Creek, T. 2 N., Rs. 44 and 45 E., Idaho.

the Absaroka overthrust brings the Beckwith formation into contact with the Wells formation on the west. The phosphate occurs between these two faults, immediately beneath a massive ledge of Rex chert 50 feet or more thick and above a bed of white limestone, which is the upper part of the Wells formation. A sample of phosphate rock was gathered at this locality (H, Pl. I) from the Phosphoria formation, which is about 375 feet thick. A phosphate bed $3\frac{1}{2}$ feet thick yielded 31.69 per cent phosphorus pentoxide (P_2O_5), or 69.4 per cent tricalcium phosphate ($Ca_3(PO_4)_2$). A short distance east of the fault lies the contact between the Beckwith formation and the Twin Creek limestone, both of which strike northwest and dip 30° – 35° SW. The general relations observed along Rainy Creek are shown in figure 3.

Phosphate deposits are also exposed on the north fork of Rainy Creek in much the same relations as on the south fork. H. Corbet, of Irwin, Idaho, states that a coal claim has been staked on these deposits and attempts have been made to develop it. Mr. Corbet was primarily interested to know if the material was coal, as he wished to determine whether or not a coal supply for Swan Valley could be obtained at this place. He furnished a sample of rock taken from the prospect on the North Fork (I, Pl. I), which yielded 17.08 per cent phosphorus pentoxide (P_2O_5), or 37.4 per cent tricalcium phosphate ($Ca_3(PO_4)_2$), and gave evidence of organic matter. The rock consists of a black carbonaceous shale such as is often found associated with the richer phosphate beds.

PALISADE CREEK.

Similar phosphate rock occurs between the two faults on Palisade Creek above the upper lake, which likewise has been prospected for coal. A sample of phosphate rock from this locality (G, Pl. I) reported to show the physical characteristics of coal was analyzed and yielded 12.69 per cent phosphorus pentoxide (P_2O_5), or 27.8 per cent tricalcium phosphate ($Ca_3(PO_4)_2$), and gave good evidence of organic matter.

Structural observations on the divide between Rainy and Palisade creeks east of the anticline that passes through Baldy Mountain and west of the first fault shown on Rainy Creek show that immediately east of Baldy Mountain is a low syncline in Carboniferous rocks whose axis strikes northwest. Immediately east of this low syncline is a gently folded anticline whose axis strikes N. 60° W. and exposes along its crest beds of Pennsylvanian age, a little lower stratigraphically than the beds exposed in the syncline. Farther east is another shallow syncline, to the east of which is a second sharply folded anticline whose east limb is cut by the fault. The west limb of the anticline strikes N. 60° W. and dips 30° SW.; the east limb strikes N. 40° W. and dips 70° NE. The beds exposed along the divide between Rainy and Palisade creeks appear to consist chiefly of the Madison limestone and the overlying Wells formation. At no place west of the fault in these two synclines were phosphate beds or the Phosphoria formation seen. In the block between the two faults, the eastern of which is the Absaroka, the Phosphoria formation is present and deposits of phosphate are known to occur. Similar deposits occur east of the Absaroka fault but lie at a considerable depth below the surface, though the exact depth can not be determined until a detailed stratigraphic study of the region has been made.

ELK CREEK.

No deposits of phosphate rock were seen near the line of traverse along Elk Creek. The main part of the Snake River Range is composed of rock of Paleozoic age. The rocks in this vicinity are highly folded and are broken by faults, the exact position of which has not been ascertained except along the line of traverse. Two main anticlinal folds trending in a northwesterly direction cut across Elk Creek, and with these folds are associated numerous minor folds and flexures. On the upper part of Elk Creek the same fault relations were observed as along Rainy and Pine creeks, but here the streams have cut through the phosphate beds and are now intrenched in rocks of the

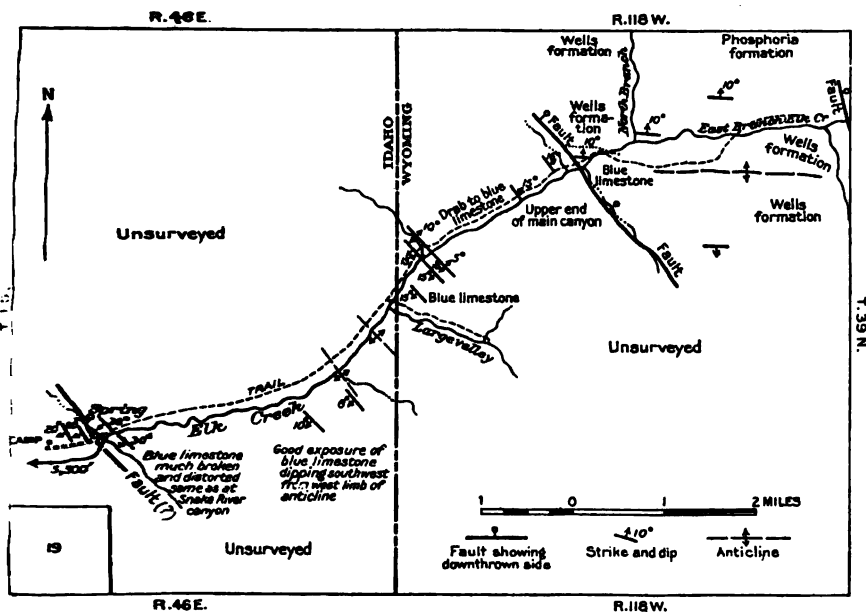


FIGURE 4.—Map showing traverse along Elk Creek, T. 1 S., R. 46 E., Idaho, and T. 39 N., R. 118 W., Wyo.

Wells and underlying formations. In the area between the two faults the phosphate-bearing beds are present in the ridges both north and south of the stream. From the traverse along the valley it appears that phosphate deposits occur near the crests of some of the ridges, but no attempt was made to trace the horizon or examine the separate hills to determine the presence and thickness of the phosphate beds. The general relations and the attitude of the phosphate bed along Elk Creek are shown in figure 4.

From the examination made in this vicinity it is apparent that no phosphate deposits occur in the Snake River Range west of the western fault shown in figure 4, as this part of the range consists of rocks older than the phosphate formation. The western flank of the range

may terminate abruptly along a fault or it may represent the eastern limb of a closely folded syncline, but in either case the phosphate beds are not present between Snake River and the fault. Owing to the heavy cover of gravel, recent conglomerates, and lava flows that masks the underlying Paleozoic rock along the west flank of the range, the structure has not been satisfactorily determined.

INDIAN CREEK.¹

A foot-paced traverse was made on both the North and South forks of Indian Creek. The structure of the west flank of the Snake River Range in this vicinity is very similar to that on Elk Creek, in that the older Paleozoic rocks are partly concealed by gravel and nearly horizontal conglomerate beds that dip gently away from the mountains. It appears, however, that the west base of the main range coincides approximately with the synclinal axis in the Paleozoic rocks that cross Indian Creek just below the forks. The main part of the Snake River Range in this vicinity consists of Paleozoic rocks in every way similar to those observed on Elk, Rainy, and Pine creeks. The main anticline of the range crosses both the North and South forks of Indian Creek and is cut out by a fault a short distance south of the South Fork. This anticline probably represents the southward extension of the anticline that passes through Baldy Mountain east of Irwin and is the same as that observed on Palisade and Elk creeks. All the rocks west of the fault shown in the accompanying map (fig. 5) are older than the Phosphoria formation, and no phosphate deposits are known to occur in this part of the range. Beds of Pennsylvanian (Wells) age are exposed east of the fault.

The sandstones of the Wells formation are overlain by the Phosphoria formation, which in turn is overlain by the Woodside and Thaynes formations. The traverse on the South Fork of Indian Creek was not carried far enough up the stream to encounter the phosphate beds, but it is apparent from the examination made that they are present on the upper part of this stream. On the North Fork of Indian Creek the phosphate bed was encountered immediately beneath the massive Rex chert member and immediately above the limestone member at the top of the Wells formation. The Phosphoria formation here is approximately 400 feet thick, and the phosphatic series about 75 feet thick. The rich phosphate bed was not measured but is believed to be from 3 to 4 feet in thickness. A sample collected from the phosphate bed on the north side of the creek (A, Pl. I) yielded 32.85 per cent phosphorus pentoxide (P_2O_5), or 71.78 per cent tricalcium phosphate ($Ca_3(PO_4)_2$).

The general relations of the Phosphoria formation to the overlying and underlying formations are shown in figure 5.

¹ This stream should not be confused with the Indian Creek in the Caribou Range.

Similar relations to those observed here may be expected along the upper part of South Fork of Indian Creek. On the divide between the two forks the phosphate deposits extend much farther west and may extend to the fault contact. The high ridge to the east is apparently underlain by the phosphate bed.

SNAKE RIVER.

The structural conditions along the west base of the Snake River Range on Snake River are similar to those observed on the streams to the north. The Paleozoic beds are closely folded and compressed, and in places they appear to be overturned. At the mouth of the

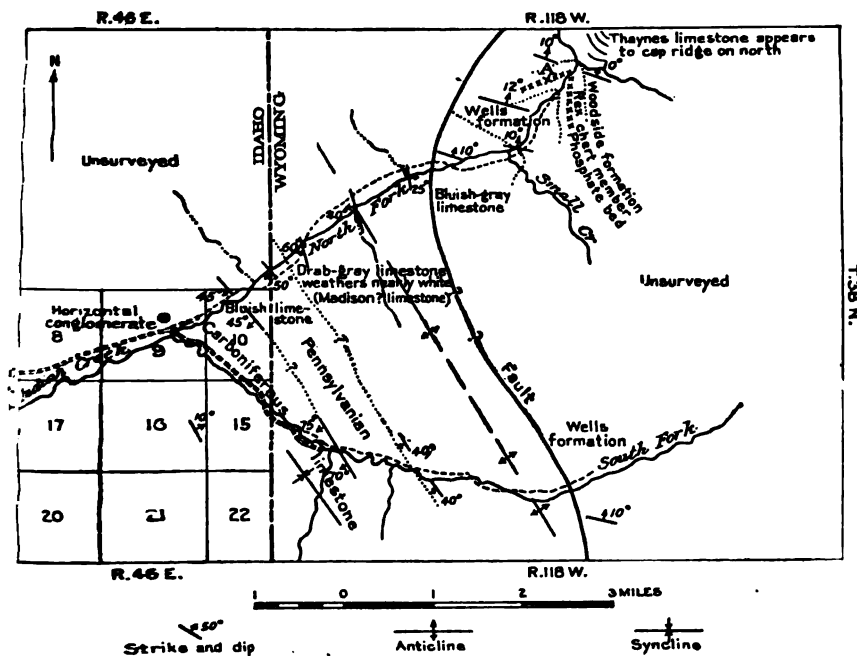


FIGURE 5.—Map showing traverse along Indian Creek, T. 2 S., R. 46 E., Idaho, and T. 38 N., R. 118 W., Wyo.

Snake River canyon the beds show clearly in wavy lines along bedding planes the effect of the compression strain. The anticlinal axis observed on Indian Creek is not present on Snake River, as it is cut out by the western fault. The Paleozoic beds west of the fault are the same as those on Indian Creek but here represent only the west limb of the anticline. The structure on Snake River in the belt between the western fault and the Absaroka fault is more complex than that observed on Indian Creek, as there are here three distinct anticlines trending approximately north. In this belt the phosphate deposits occur well up on the higher hills, there being no deposits of phosphate along the line of traverse, as Snake River has cut through

the Phosphoria formation and exposes older beds throughout its course from the lower end of the canyon up to the Absaroka fault. On the north side of Snake River beds of the Phosphoria formation were seen in the higher hills and probably represent the southward extension of the beds observed along Indian Creek. It is not known whether the phosphate beds occur in the hills between Greys River and Snake River on the south side of the Snake. East of the Absaroka fault and west of the Wyoming Range the Phosphoria beds lie at a great depth, as in this area the surface exposures consist of beds of Cretaceous age. The outcrop of the Phosphoria formation along the west side of the Wyoming Range is described on pages 23-24. The

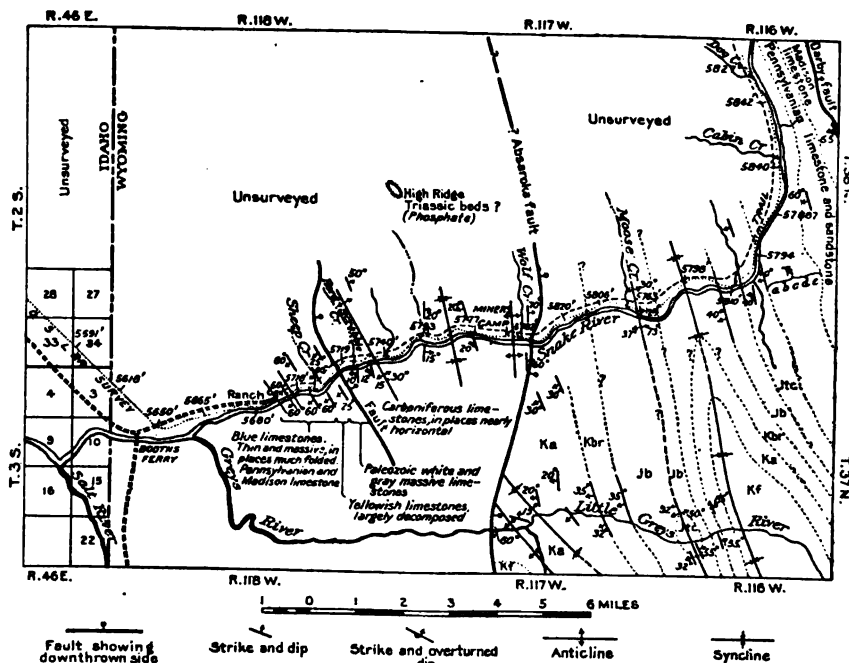


FIGURE 6.—Map showing traverse along Snake River canyon, Tps. 37 and 38 N., Rs. 116, 117, and 118 W., Wyo.

structure between the Absaroka fault and the Wyoming Range, so far as known, is shown in figure 6.

On this part of Snake River at least one pronounced anticline and one syncline that trend about north cross the river at nearly right angles. It is not known what beds are exposed along their axes in the region of Snake River. If the beds are closely folded, as they are in the vicinity of Little Greys River, beds of Jurassic age probably crop out along the crest of the anticline and beds of Cretaceous age along the axis of the syncline. The coal-bearing Frontier or Bear River formation may be present in the syncline as coal has been

reported in this belt on Snake River. No examination was made of the beds along Snake River between the Absaroka fault and the mouth of Bailey Creek, and it is not known what beds are exposed at the surface.

In the course of this reconnaissance examination no observations were made south of Snake River, but it is known from earlier work in this region that the phosphate deposits occur at several points farther south. South of Virginia Peak the central part of the range consists of a syncline along which beds of Triassic age are exposed. The Salt River Range is terminated on the east by the Absaroka fault, which in this locality brings Mississippian limestone into contact with Cretaceous beds. The western part of the range consists of a northwestward-trending anticline, in places overturned. The phosphate beds crop out along the west flank of this anticline and along both limbs of the syncline in the central part of the range. Toward the north along both anticline and syncline older beds appear at the surface, and west and north of Virginia Peak all the phosphate beds have been eroded except possibly along the west flank of the anticline, where they may be concealed by the gravel and alluvium along Salt River. Whether or not the northwestward-trending anticline observed in this part of the Salt River Range is the southeastern continuation of the anticline observed near the mouths of McCoy and Bear creeks, east of the Caribou Range, was not determined.

As the Paleozoic formations run nearly parallel to the Salt River Range it is probable that south of Virginia Peak the phosphate deposits are found generally along the range, usually well up toward its crest, and there is reason to believe that they are not subject to great variations in richness along the outcrop. In 1910 C. L. Breger recognized the phosphate beds in the canyon of Swift Creek east of Afton, Wyo. He found at the base of the phosphate beds about 42 feet of gray limestone, overlain by 40 to 78 feet of soft shaly beds, including phosphate rock, overlain in turn by more than 100 feet of massive to thin-bedded chert. It is believed that there are two phosphate beds in the shaly strata here, the lower one at the base and the upper one about 45 feet above the base. The thickness of either is still unknown, but pieces of the float from the upper bed, consisting of massive black oolite, yielded on analysis 67.4 per cent of tricalcium phosphate. Since the preparation of this report a reconnaissance examination for phosphate in the Salt River Range has been made by G. R. Mansfield.¹

¹ Mansfield, G. R., A reconnaissance for phosphate in the Salt River Range, Wyo.: U. S. Geol. Survey Bull. 620, pp. 331-347, 1915.



BIGHOLE MOUNTAINS AND WYOMING RANGE.

GENERAL FEATURES.

The Bighole Mountains and Wyoming Range lie immediately northeast of the Snake River and Salt River ranges and are, like them, terminated on the east by a pronounced fault. Deposits of phosphate have been observed at several places in these ranges, for the most part on the west side of the mountains, whereas in the Snake River Range the deposits lie on the east flank of the main mountain range. Phosphate outcrops were observed at several localities on the west slope of the Wyoming Range southeast of Snake River. On Snake River in the vicinity of Counts's ranch, several miles below the mouth of Hoback River, the Phosphoria formation and the overlying and underlying rocks were noted on the southwest flank of the range. In the Bighole Mountains the same beds were observed in the vicinity of station 39, south of Victor, Idaho, and on the west flank of the range in the vicinity of stations 40 and 42, but were not seen in the vicinity of the headwaters of Pine Creek, where the road crosses the divide from Teton Basin to Conant Valley on Snake River. It is believed that the phosphate beds here are cut out by the fault, as Cretaceous beds occupy the crest of the ridge. The phosphate outcrop was not found in the Bighole Mountains west of Victor and Driggs, Idaho, as the 8-inch cover of snow concealed it from view. From the structure and from the overlying and underlying beds it appears that deposits of phosphate occur in this part of the range, although locally, as in the upper part of Pine Creek, the phosphate bed may lie at a considerable depth below the surface. Although the beds have not been traced for any distance beyond the locality where they were examined, it is reasonable to assume that they are present in this range from the headwaters of Canyon Creek, west of station 42, southeastward to Snake River.

WYOMING RANGE SOUTHEAST OF SNAKE RIVER, IN THE VICINITY OF BAILEY CREEK.

In the summer of 1906, while the writer was mapping the geology southeast of Snake River, he recognized the Park City beds, which include the Phosphoria formation, on the west flank of the Wyoming Range and traced them from the southern part of Wyoming northward to Snake River. Phosphate samples were obtained at several localities toward the south, but none were collected in the vicinity of Snake River. The Phosphoria formation, including the phosphate bed, was not mapped separately at this time but grouped with the overlying Woodside and Thaynes formations. It is reasonably certain that the bed of phosphate occurs in this part of the range and overlies the Pennsylvanian sandstone and limestone that form the west slope of the range southeast of Snake River.

WYOMING RANGE IN THE VICINITY OF SNAKE RIVER.

In the vicinity of Counts's ranch, on the opposite bank of Snake River in the NE. $\frac{1}{4}$ sec. 32, T. 39 N., R. 116 W., there is a good exposure of the phosphate rock. The black material has long been supposed to be coal, and the deposit has been considered by the inhabitants as a possible source of coal for local use. Here, as at other places farther south, the deposit consists of approximately 60 feet of shale representing the phosphate rock. The richer phosphate beds alternate with black phosphate, shale, and limestone that carry a small amount of tricalcium phosphate. These phosphate beds are not the northward extension of the beds observed on the west flank of the range east of Bailey Creek but lie on the east side of the Darby fault. The northward extension of the Bailey Creek phosphate beds on the west side of the range passes beneath the gravel along Snake River and probably lies some distance west of the exposures at Counts's ranch. The beds on Snake River east of the Darby fault in the vicinity of Counts's ranch crop out in a closely folded anticline that crosses Snake River in a southerly direction and is broken by one or more minor faults. The structure of the range is much more complex in this vicinity than it is farther south, and considerable time would be required to work out the details and trace the phosphate outcrop northward to the vicinity of station 39, southwest of Victor, Idaho. Eliot Blackwelder visited the Snake River locality in 1910 and measured the following detailed section, which represents fairly well the Phosphoria formation in this part of the range:

Section of phosphatic beds in the northwest bank of Snake River opposite Counts's ranch, in sec. 32, T. 39 N., R. 116 W., Wyo.

	Ft.	in.
Top overlain unconformably by Tertiary conglomerate.		
Shale and limestone, gray-buff to brown, with thin black phosphatic seams here and there.....	20	
Phosphate rock, brown and nodular (21.2 per cent tricalcium phosphate).....	2	6
Phosphate rock, black, soft, and shaly (random sample, 68.5 per cent tricalcium phosphate).....	9	
Chert, dark gray.....	12	
Shale, black and probably phosphatic.....	4	
Chert and seams of limestone, passing gradually upward into cherty limestone with black shale partings.....	33	
Limestone, earthy buff to gray, with black chert nodules.....	20	
Sandstone, soft and white, with thin beds of gray chert.....	26	
Sandstone, fine, white, and very soft.....	6	
Limestone, pearl-gray, argillaceous.....	22	
Phosphate rock, black and oolitic.....		2½
Chert, massive, gray.....	6	

	Ft.	in.
Alternating thin beds of soft oolitic phosphate rock and hard black limestone (probably about 20 per cent tricalcium phosphate).....	5	10
Massive brown phosphate rock (66.3 per cent tricalcium phosphate).....	2	5
Limestone, brittle, black.....	1	
Phosphate rock, soft, black, granular (20 to 30 per cent phosphate).....	3	
Limestone, brittle, black.....	2	6
Phosphate rock, soft and shaly (29.6 per cent phosphate).....	4	6
Limestone, brittle, black.....	2	
Phosphate, black, shaly, and granular, with lenses of black limestone (average of entire bed, 20.3 per cent tricalcium phosphate).....	12	
Limestone, brittle, black.....	1	3½
Phosphate rock, soft, shaly, and granular, with lenses of black limestone (average of entire bed, 31.2 per cent tricalcium phosphate).....	12	
Limestone, hard, dark gray.....	9	
Sandstone, soft, argillaceous, gray.....	8	
Shale and limestone, smoky gray to buff.....	22	
Quartzite, white to buff (Wells formation).....	47	

BIGHOLE MOUNTAINS SOUTH OF VICTOR, IDAHO.

In the vicinity of station 39, in T. 2 N., R. 45 E., south of Victor, Idaho, the series of rocks exposed is the same as that observed at Bailey Creek in the Wyoming Range, south of Snake River. (See fig. 6, p. 48.) The beds have practically the same relations and are terminated on the northeast by a pronounced fault, believed to be the northward extension of the Darby fault, that separates them from the beds along the west flank of the Teton Mountains in the south end of Teton Basin. The oldest beds exposed in the vicinity of station 39 lie near the east base of the Bighole Mountains, where Carboniferous rocks, probably of Pennsylvanian age, occur. The Carboniferous rocks are exposed for a distance of several miles in a northwesterly direction along the fault contact, but the outcrop is cut out entirely by the fault before the beds pass beneath the gravels and valley fill along the west side of Teton Basin, or to reappear several miles to the northwest, in Tps. 4 and 5 N., R. 44 E., where they form a pronounced range of hills facing Teton Basin. The summit of the hill on which station 39 is located consists of Nugget sandstone that strikes N. 10° W. and dips 45° S. This sandstone is overlain by a considerable thickness of dark-gray limestone and shaly beds of the Twin Creek formation. These beds may represent the eastern extension of the Twin Creek limestone observed on the upper part of Rainy Creek, as the strike and dip are in the same direction. It is very probable, however, that there is another anticlinal fold between these two localities. No examination

tion was made of the intervening area, and the structure in this part of the range may be more complex than it appears from a distance. It is not probable, however, that the phosphate beds are exposed at the surface along a line joining these two localities. The Phosphoria formation and the overlying formations from the Phosphoria to the Nugget sandstone appear to be present in their normal position on top of the Carboniferous rock between station 39 and the crest of the range northeast of station 40, west of the Darby fault. As the ground was covered by a heavy fall of snow at the time of the writer's visit neither the phosphate bed nor any fragments of phosphate float were found, but the general structure of the region and the presence of the accompanying formations indicate that the Phosphoria formation occurs here and can no doubt be readily found under favorable conditions.

NORTH END OF BIGHOLE MOUNTAINS.

Northwest of station 39 along the strike of the beds all the formations overlying the hard pink sandstone (Nugget sandstone) apparently extend to stations 40 and 42 and beyond. There appear to be some minor displacements and secondary folds, but on the whole the structure is comparatively simple. Cretaceous beds form the main part of the divide where the road from Victor, Idaho, to the Snake River valley crosses the range. These beds contain coal and are believed to be of Bear River and Benton (Colorado) age and equivalent to the Bear River and Frontier coals in western Wyoming, south of Snake River. Whether or not the coals are continuous along this belt or whether the Frontier formation is present only in places between the Darby and Absaroka faults from Snake River northward to Canyon Creek, where the older beds are concealed beneath the lava flow, or whether the coal beds in this part of the range all belong to the Bear River formation, was not determined. Much of this area has never been mapped geologically, and coal prospecting has been restricted largely to the vicinity of Pine Creek, where considerable work has been done during 1911 and 1912 with more or less success.

The Carboniferous beds and those immediately overlying them appear to be cut out by the fault a short distance northwest of station 39, or they may have been eroded and lie buried beneath the gravels along Pine Creek, on the west side of Teton Basin. More detailed work will no doubt show what has become of these beds in the region of Pine Creek southwest of Victor. The entire series of Carboniferous rocks and overlying beds reappear north of station 40 and are apparently continuous from this locality northwestward to station 42 and beyond, where they pass beneath the lava-covered plains along the headwaters of Canyon Creek. The oldest beds in

the section occur north of station 40, and it is believed that these beds are older than Mississippian. The crest of the ridge at station 42 consists of Madison limestone that strikes northwest and dips for the most part southwest. A little farther northeast, along the fault escarpment at the northeast extremity of the ridge, occur quartzites of Pennsylvanian age that strike north and dip 10° – 65° E. Minor folding and faulting were observed along this part of the range, but time was not available to work out the structure in detail. Southwest of station 42 the beds strike N. 40° W. and dip 30° SW., and the entire series of beds overlying the Carboniferous are as fully developed in this vicinity as they are southwest of stations 39 and 40. The crest of the hills on which station 40 is located, like that at station 39, consists of hard pale-red or pink sandstone, which in places is almost quartzitic. For a considerable distance this ridge forms the main divide between Snake River and Teton Basin and is capped by this heavy massive quartzite or sandstone, which is probably equivalent to the Nugget sandstone of western Wyoming and eastern Idaho. Between this sandstone and the uppermost Carboniferous beds, composed of drab and gray cherty limestone, occurs a series of deep-red arenaceous shales and sandstones, with associated gray and drab limestone, which form a wide belt of brilliant-colored exposures in the northeast face of the ridge at station 40 and can be seen from a distance passing to the southwest of station 42 and beyond until they disappear beneath the lava plains. At the base of this series, overlying the Pennsylvanian beds, is the Phosphoria formation. Owing to the heavy cover of snow it was not practicable to try to locate the phosphate bed or to measure the thickness. From what is known of the geology and structure of this part of the range and from the reported prospects along the headwaters of Canyon Creek, where the continuity of the phosphate bed has been shown, it seems reasonably certain that the phosphate deposits are present throughout this part of the Bighole Mountains.

St. John,¹ in his report on the "Pierres Hole" (Bighole) Mountains, gives a section through station 40 and a profile showing the relations of the beds to one another in that part of the range along a line that passes through stations 40 and 42. The entire section described by him has not been examined, but it appears that the 2,000 feet of beds in his section numbered from 1 to 14 represent the Carboniferous and underlying beds. It is reasonably certain that they include beds of Pennsylvanian and Madison (lower Mississippian) age, and they may include some older beds at the base. The 2,500 feet of beds numbered from 15 to 26 represent the Phosphoria formation, Woodside formation, Thaynes limestone, Ankareh shale, and Nugget sandstone. The 1,200 feet of beds numbered from 27 to 34 probably

¹ St. John, Orestes, U. S. Geog. and Geol. Survey Terr. Eleventh Ann. Rept., pp. 425, 427, 1879.

represent the Twin Creek limestone. The 540 feet of beds numbered from 35 to 38 represent part of the Beckwith formation. It appears from his descriptions that this section contains no part of the overlying Cretaceous beds.

Northeast of station 42 a pronounced thrust fault, which is believed to be the northwestward extension of the Darby fault, brings the Carboniferous beds into contact with the Cretaceous and underlying beds on the east. The Cretaceous beds east of the fault belong to the Frontier formation and are of Benton age. In a hard ledge of sandstone on Packsaddle Creek, in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 24, T. 5 N., R. 43 E., the writer found numerous fragments and several complete casts of *Inoceramus labiatus*, *Inoceramus erectus*, and other associated Frontier species, which place these beds and their associated coals in the Frontier formation. Several beds of coal occur in this formation and are discussed in more detail under the heading "Coal." The Frontier beds near the fault line strike N. 20°-35° W. and dip from 50° S. 70° W. to 60° S. 65° W. Toward the east at right angles to the beds the dip flattens slightly as far as the ridge in secs. 19, 30, and 32, T. 5 N., R. 44 E., which is composed of Jurassic beds. This ridge trends northwest and the beds dip 54° SW. East of the ridge the Frontier formation observed on the west side is again encountered. A few coal prospects have been opened in these beds, but they have not been thoroughly prospected. The beds strike north and dip 10° W.

The occurrence of Frontier coals both east and west of the Jurassic ridge, all of which dip toward the west, indicates an overturned anticline or a fault along the east side of the Jurassic ridge, which duplicates the Cretaceous beds. The structure is somewhat complex, and more detailed work is required to determine accurately the relation of the coal beds on the east and west sides. The overturning of the anticline, if it occurred, was probably due to the large thrust movement from the west. East of the anticline is an overturned syncline, east of which in turn is another low, flat anticline that probably represents the western margin of the broad, open synclinal trough of the Teton Basin. The Teton Basin syncline and the low anticline along its western margin are for the most part concealed beneath Tertiary lavas. The writer's observations in this part of the Bighole Mountains, made during a brief reconnaissance when much of the ground was covered by snow, agree fairly well with the results reported by St. John.¹ They do not, however, confirm his conclusions regarding the fault east of station 42, for this fault is thought to be a thrust fault instead of a normal fault as shown in his profile, which passes through station 42 across the north end of the range.

¹ St. John, Orestes, op. cit., pp. 430, 432, pl. 38.

No. 1 of St. John's section through station 42 represents the Tertiary lava that conceals the underlying formations in the Teton Basin. These beds dip about 15° E. Beds 2 to 4 represent in part the Frontier formation and the underlying Cretaceous rocks. Beds 5 to 12 represent the Jurassic beds exposed in a prominent ridge east of station 42 and are chiefly of Beckwith age, although some Twin Creek limestone is exposed in parts of the ridge. Beds 5 and 12 are believed to represent the same stratigraphic ledge. Beds 13 to 17 represent Cretaceous beds lying between the Jurassic ridge and the Carboniferous beds west of the Darby fault and include the Frontier formation. Bed 18 represents the Pennsylvanian and the Madison limestone west of the fault that forms the eastward-facing scarp of the main mountain range. The Jurassic ridge east of station 42 and the associated Cretaceous beds both east and west of the ridge disappear beneath the Tertiary lavas within a short distance to the north, but toward the southeast they extend to the western border of Teton Basin, where they have been eroded and are now covered by recent deposits. Coal beds of the Frontier formation may also occur beneath a large part of the Teton Basin east of the easternmost anticline observed, but no exposures of coal were seen on the east side of the Jurassic ridge east of the exposures on Horseshoe and Packsaddle creeks.

Although the phosphate beds probably underlie all of the Teton Basin syncline from the Darby fault east to the phosphate exposures along the west flank of the Teton Mountains east of Driggs and Victor, Idaho, no exposures of these beds were seen between the Darby fault and the east side of Teton Basin. If present these beds lie at a considerable depth below the surface.

TETON MOUNTAINS.

The Phosphoria formation is exposed in the Teton Mountains only near the south end along the western flank of the range. The east side of the range is bounded by a pronounced fault, and all the beds composing the range west of the fault to the west slope are older than the Phosphoria formation. Along the west slope of the range, where the Phosphoria formation crops out, the phosphate beds are poorly exposed. Farther north the lower slopes of the range are covered by gently westward-sloping sheets of Tertiary lava that conceal the phosphate and underlying beds. Phosphate deposits were observed by the writer in 1911 along the west slope of the range east of Victor, Idaho, between Moose and Fox creeks, but no section of the bed was measured. Eliot Blackwelder, in 1910 and 1912, examined the beds from the vicinity of Alta, Wyo., where they pass beneath the lava cover, southward to the south end of the Teton Basin. At the south end, where the Teton Mountains mergewith

the Bighole Mountains, the phosphate beds that underlie Teton Basin become folded in a sharp, compressed syncline between the Teton Mountains on the east and the beds west of the Darby fault northeast of station 39. The outcrop of the phosphate bed along this part of the range is shown on Plate I. Near the mouth of Coal Creek, in T. 41 N., R. 118 W., Wyo., an old coal prospect dump shows a soft black material which represents the location of the phosphate bed. The tunnel was dug about 25 years ago on the supposition that a valuable bed of coal could be opened at this place. The prospect is now badly caved, and a good section of the bed can not be measured without considerable prospecting or digging. Blackwelder, who visited the prospect in 1910, states that the phosphate bed appears to be several feet thick and ranges from soft black oolite to earthy phosphate rock. The oolite yields 52.2 per cent of tricalcium phosphate, and a general sample of all the material on the dump yields 20.8 per cent of tricalcium phosphate.

In 1911 John Cluff, of Victor, Idaho, was opening a prospect in the vicinity of sec. 15, T. 41 N., R. 118 W., with the expectation of finding a local supply of coal for Victor and the Teton Basin. He reports that the beds here strike northwest and dip 45° SW., and that the supposed coal bed is 5 feet thick. A sample of this material sent in for analysis yielded a trace of phosphorus pentoxide (P_2O_5) and showed evidence of organic matter supposed to be coal. From the sample it appears that the prospect was opened on the phosphatic series and represents the carbonaceous shale accompanying the main phosphate bed, which in places yields from 50 to 80 per cent tricalcium phosphate.

The only section of the phosphate beds available along the west flank of the Teton Mountains was measured by Eliot Blackwelder, in 1912, while mapping a part of the Grand Teton quadrangle. Most of the Phosphoria formation, the top of which has been in part removed by erosion and the base of which indicates a slightly eroded contact, is well exposed on the slope of the ravine between Darby and Fox creeks in what will probably be when surveyed sec. 29, T. 43 N., R. 188 W.

Section of Phosphoria formation on Darby Creek, Wyo.

[Measured by Eliot Blackwelder.]

	Feet.
Brown, cherty sandstones with tubular bodies of chert.....	30+
Massive friable gray dolomite with chert nodules and traces of marine fossils.....	19
White soft sandstone.....	1.5
Chiefly thin-bedded yellow and pink dolomite, chert and sandstone; concealed in part.....	21
Gray to buff shaly dolomite and chert.....	8
Yellow shale and argillaceous dolomite.....	7.5

Massive gray oolitic phosphate rock, containing 68.2 per cent tri-calcium phosphate.....	Feet. 0.8
Olive-gray chert.....	1.9
Gray oolitic phosphate rock, containing 73.2 per cent tricalcium phosphate.....	.9
Massive gray chert with dolomite.....	4
Fine-grained oolitic phosphate rock, containing 71.8 tricalcium phosphate.....	.6
Dense gray dolomite.....	.3
Pisolithic blue-black phosphate rock, containing 72.9 per cent tricalcium phosphate; white selected coarse pisolithic layer contains 75.9 per cent.....	1.5
Massive gray chert.....	1.1
Gray oolitic phosphate rock, containing 76.4 per cent tricalcium phosphate.....	.8
Dark-gray sandy phosphatic breccia, at the base of which is a slightly eroded contact.....	.5
	<hr/> 99.4

JACKSON HOLE AND VICINITY.

No detailed examination has been made of the area in the vicinity of Jackson, Wyo., between the Teton, Hoback, and Gros Ventre mountains. Phosphate deposits are known to occur on the north and south sides of the Gros Ventre Mountains and at several places along the Hoback Range. The geology, structure, and phosphate deposits of these ranges are discussed more fully in previous publications.¹ The structure in the vicinity of Jackson is complex and is as yet only partly understood, owing to the widespread cover of the older rocks by Tertiary beds and alluvium along Snake River. For this reason exposures of phosphate rock are meager, and a detailed examination is necessary to determine the structure and distribution of the phosphate beds in this locality. Although phosphate exposures have not been found, it is known that phosphate occurs in this area. In secs. 17, 18, 19, and 33, T. 41 N., R. 116 W., fragments of phosphate rock were found in such relations as to indicate that the phosphate bed lies immediately beneath the surface. In the NW. $\frac{1}{4}$ sec. 33 Eliot Blackwelder in 1911 found in the soil and débris at a definite horizon just above the Pennsylvanian sandstone abundant quantities of weathered black oolitic phosphate rock, which occurs near the base of the Phosphoria formation. Samples of this float on analysis yielded 61.3 per cent of tricalcium phosphate. Outside of these two localities and the area south of Jackson, at the north end of the Hoback Range, no deposits of phosphate are known to occur in the area east of Snake River and north of the Wyoming Range.

¹ U. S. Geol. Survey Bull. 470, pp. 452-481, 1911; Bull. 543, 1914.

DEVELOPMENT OF PHOSPHATE DEPOSITS.

The phosphate industry in the Rocky Mountain region has made progress slowly. In 1913 approximately 5,919 long tons of phosphate rock was mined, of which 5,053 tons was sold for \$18,167, an average price of \$3.57 a ton. This production was less than 0.5 per cent of the entire phosphate production of the United States in 1913. In 1916 the proportion was only 0.08 per cent. Part of this lack of progress may be attributed to the fact that some of the early properties have been involved in litigation, part to the high cost of transporting the phosphate to localities where it is needed for depleted soils, and part to the fact that as yet comparatively few agriculturists fully appreciate the increased production possible by the use of phosphate fertilizer.

Thus far phosphate rock has been shipped in the West for commercial use from only a few localities in the West. All the localities at which small mines have been opened and from which rock has been shipped are in the Bear Lake region, in southeastern Idaho, northeastern Utah, and western Wyoming, where the deposits were first discovered. Slight as the development has been in these older localities, there is still a marked contrast between them and the area described in this report, for in this area the phosphate deposits have received practically no attention from the prospector, and their very existence seems to be unknown to him or to the inhabitants. What little prospecting has been done along the phosphate outcrop was undertaken with the idea of opening coal mines from which a supply of coal could be obtained for local use. The phosphate beds have been prospected in Wyoming for coal on Snake River south of Jackson Hole and at the mouth of Coal Creek, near the southeast end of Teton Basin; and in Idaho on Patterson Creek, on North Fork of Rainy Creek and Palisade Creek east of Swan Basin, in Burns Canyon, and on the headwaters of Canyon Creek, in the Bighole Mountains. Although coal has been reported from these beds at many places in the mountains north of Snake River, active prospecting was soon abandoned at these places and most of the prospect pits and tunnels are now so badly caved that they can not be explored and the phosphate beds can not be measured without much additional labor. Most of the old prospects were abandoned because the prospectors failed to discover coal of good grade and the real nature of the beds apparently remained unknown.

No detailed work has been done in this field on which to base an estimate of the quantity of phosphate rock available. It is apparent, however, from the reconnaissance examination that in the Snake River Range, Bighole Mountains, and Teton Range, particularly along the east side of Teton Basin, a large amount of phosphate is

present. Every acre underlain by a flat bed of phosphate 4 feet thick would yield approximately 14,000 tons, and where the phosphate bed is steeply tilted the amount beneath an acre is much greater.

The phosphate beds along the southeast side of Teton Basin and in the Bighole Mountains are near the tracks of the Victor branch of the Oregon Short Line Railroad. In the Snake River Range they lie some distance from the Yellowstone branch of the Oregon Short Line, but are readily accessible by wagon roads up the Snake River valley from Rexburg and Rigby, Idaho. The Rigby route is one that offers no unusual difficulties for the construction of a railroad which with a short haul would place the phosphate on the main line of the Oregon Short Line from Butte, Mont., to Salt Lake City, Utah. The Oregon Short Line has made two preliminary surveys from Idaho Falls, Idaho, up Snake River to Jackson, Wyo., the first in 1905 and the second in 1912. As soon as this road is built it will bring railroad shipping facilities in the Snake River Range within a few miles of the phosphate deposits, as the road will extend along the west base of the range approximately parallel to the phosphate outcrop. The position of the alinement survey is shown on the map (Pl. I) by a single black line along Snake River from Jackson, Wyo., to the west boundary of the area, west of Prospect, Idaho. The completion of this railroad would materially alter the economic conditions of this part of Idaho and Wyoming, increase the agricultural population in Jackson Hole and Snake River and Salt River valleys, tend to make the district more popular than ever as the best hunting ground for big game in the United States, and greatly stimulate mining activities in the phosphate and coal fields.

UTILIZATION OF ROCK PHOSPHATE.

The mining of rock phosphate in eastern Idaho, Utah, and western Wyoming is controlled almost entirely by the concerns that manufacture and sell phosphate fertilizer, so that quotations of market value of the raw rock at the mines are not readily available and do not represent competitive values. All the rock phosphate now shipped from eastern Idaho or western Wyoming is sent to the Pacific coast, where it is used in the manufacture of fertilizers. In this treatment the rock is finely ground and combined with sulphuric acid in nearly equal parts by weight, forming acid tricalcium phosphate. This material when dried and pulverized constitutes the substance sold as superphosphate.

The principal use of the phosphate rock is to fertilize farm lands that are deficient in phosphorus, one of the three essential mineral plant foods which are not ordinarily present in agricultural soils in excess of the needs of growing plants, the other two being potash and nitrates. The need for phosphate will undoubtedly become more

apparent with the deterioration of western grain lands. Furthermore, some of the virgin lands may be deficient in this material and would be improved by its application. Although, as principally used in fertilizers, phosphate is converted into the more readily soluble forms, recent experiments indicate that if the crushed rock is applied directly to the soil the phosphorus is gradually made available to the plants, and it is likely that in this form rock phosphate may find one of its most important future applications.

The chief obstacle to the development of the western phosphate industry at present is the high cost of transporting the bulky products and the lack of markets sufficiently near to warrant the exploitation of the deposits. Much of the agricultural land of the Western States is relatively new, and as its original phosphates have not been exhausted by past crops it is less in need of fertilizers, except where the virgin lands are deficient in phosphorus, than the older farm lands in thickly settled communities of the East and South.

The use of fertilizers is said to be fast increasing on the Pacific coast, also in other parts of the West where intensive farming is practiced. There will henceforth probably be a more rapidly growing market for fertilizer products in both the middle West and the far West, and it is to this territory that the western phosphate producer must look primarily for markets.

ANALYSES OF PHOSPHATE ROCK.

A number of samples representing phosphate rock in place and phosphate float were collected along the outcrop in the Caribou, Salt River, Snake River, Bighole, Wyoming, and Teton mountains, and these have been analyzed in the laboratory of the United States Geological Survey with the results set forth below. Many of these samples represent small pieces of rock from a part of the phosphate bed that is but poorly exposed. Although the material is the best at hand, the samples and analyses can hardly be considered truly indicative of the character of the material in the undisturbed bed, which may give much better results. The localities from which samples of rock phosphate or float were obtained are indicated on Plate I by letters A to J, beginning in the southeastern part of the area. Localities A to F are in Wyoming, and G to J in Idaho.

Analyses of phosphate rock from eastern Idaho and western Wyoming.
Wyoming.

Letter on Plate I.	Location.		Section of phosphate bed sampled.	Analysis of phosphate sample.				Remarks.
	T.	R.	Sec.	Al ₂ O ₃	Fe ₂ O ₃	P ₂ O ₅	Equivalent to Ca ₃ (PO ₄) ₂	
	32 N.	118 W.	25, NW. 1...				67.4	Thickness of both beds unknown. Upper bed 40 feet above lower. Section on Alton Creek.
A	38 N.	118 W.	3, NW. 1...	5.41	0.46	32.8	71.6	Indian Creek section (fig. 5, p. 47).
B	39 N.	116 W.	32, NE. 1...				21.2 68.5 20 66.3 20-30 29.6 20.3 31.2	Section on Snake River measured by Eliot Blackwelder, and separate layers sampled. See complete section, pp. 51-52.
C	41 N.	116 W.	33, NW. 1...				61.3	Collected by Eliot Blackwelder in 1912 near Jackson, Wyo.
D	41 N.	118 W.	15, SE. 1...				52.2	Phosphate bed here appears to be several feet thick. Coal Creek section.
			Dump sample.....				20.8	General sample of all the material on the prospect dump.
E	41 N.	118 W.	16, NE. 1...			Trace.		Shows evidence of organic matter. Trail Creek section.

PHOSPHATE.

63

T	43 N.	118 W.	20, N. 1/2	Foot fragment	Fl. in.			78.3	Collected by Eliot Blackwelder.
				Gray collitic rock.....	8			68.2	Darby Creek section. Measured and sampled by Eliot Blackwelder in 1912. See section, pp. 57-58.
				Gray collitic rock.....	9			72.3	
				Fine collitic rock.....	6			71.8	
				Black phosphate.....	1	6		72.5	
				Gray collitic rock.....	8			70.4	
Idaho.									
G	2 N.	45 E.	25	Supposed coal prospect.....		4.17	1.54	12.69	Pallada Creek. Unknown portion of bed. Prospected for coal. Shows evidence of organic matter.
H	2 N.	45 E.	16	Rock ledge.....	Fl. in. 3 6	.58	.61	31.69	Section on South Rainy Creek, exposure of rock-phosphate bed (fig. 3, p. 43).
I	2 N.	45 E.	8	Supposed coal prospects.....		3.91	1.44	17.08	North Fork of Rainy Creek. Unknown portion of bed. Prospected for coal. Shows evidence of organic matter.
J	3 N.	44 E.	28	Rock ledge.....	Fl. in. 4	1.79	.71	27.51	Section on Pine Creek (fig. 2, p. 42). Exposure of phosphate. No detailed section measured.
				Phosphate shale.....				16.8	Collected by Blackwelder in 1910. No section measured.
	1 S.	45 E.	32	Rock ledge.....	Fl. in. 4			28.93	Sample from 4-foot bed on north side of Black Creek; collected for desk use.

The analyses show considerable variation but they indicate the presence of some high-grade ore that contains approximately the equivalent of 70 per cent of tricalcium phosphate. The average of ore now being shipped from southeastern Idaho, northeastern Utah, and southwestern Wyoming runs about 70 per cent tricalcium or bone phosphate. Experience has shown, however, that weathered phosphate rocks are commonly enriched 3 to 5 per cent more, owing to the leaching of the more soluble lime carbonate, and that a deposit may therefore show a higher value at or near the surface than at greater depths. On the other hand, it should be remembered that commonly in a region like that examined only the harder and more siliceous fragments are found along the outcrop or exposed at the surface, and these may represent a lower value than the richer layers of the main phosphate bed.

COAL.

GENERAL OCCURRENCE.

Beds of coal have been found at several localities in this field and are at present being mined in a few places. Most of the coal beds that have been exploited are of Cretaceous age, belong to the Frontier formation, and represent the northward extension of the coal beds which are so extensively developed and on which active mines are located in southern Lincoln County, Wyo., from Cumberland northward to Fontanelle Creek, several miles north of Frontier. Beds of coal are also found in rocks stratigraphically below the Frontier formation, which probably represent the Bear River coals that have been prospected in the vicinity of Sage, Wyo., but on which no active mines are located. The coal beds in this formation consist of coaly shale with some impure, irregular lenses of coal, ranging in thickness from a few inches to 4 or 5 feet. As a rule the coaly portions of these beds are not persistent but wedge in and out. Lumps of usable coal may be obtained here and there, but commercial development on a large scale is impracticable. The coal beds are widely distributed but may readily be separated on structural features into three areas—the Willow Creek and Grays Lake area, the Pine Creek and Greys River area, and the Teton Basin and McDougal area. No special effort was made to map the coal beds in any of these areas or to collect sufficient data upon which to base a classification. Wherever possible notes on their occurrence were made, and in a general way the distribution of the coal-bearing rocks was ascertained while the phosphate beds were being examined, although the two for the most part do not occur near together. As a result of this preliminary reconnaissance examination 979,901 acres, included in an outstanding coal withdrawal in eastern Idaho, was restored to entry on May 19, 1913.

WILLOW CREEK AND GRAYS LAKE AREA.

All the coal beds prospected in the Caribou Range occur along the west side of the range from Willow Creek, east of Idaho Falls, south-eastward to the headwaters of Blackfoot River, southeast of Grays Lake. The beds are believed to be part of the Bear River formation

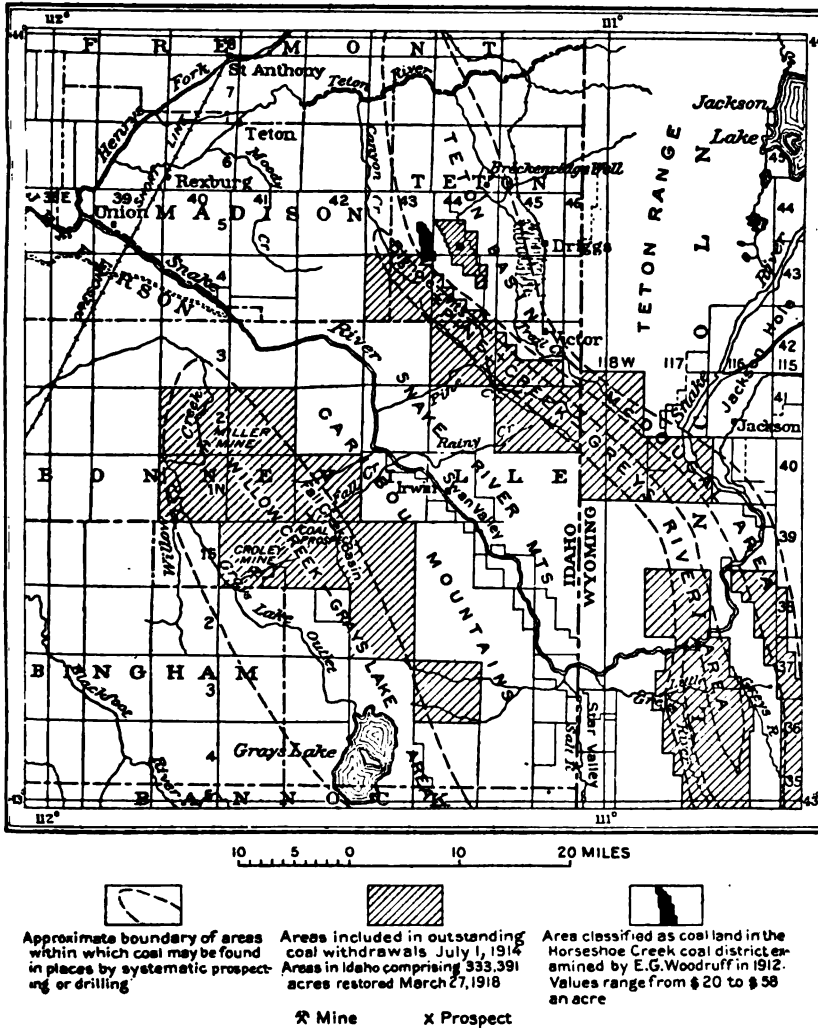


FIGURE 7.—Map showing outstanding coal withdrawals July 1, 1914, and the approximate location of the coal-bearing formations in the area examined in eastern Idaho and western Wyoming.

but may in places also include a part of the Frontier formation, although the writer has little information regarding their age or distribution. So far as known the coal has been opened at only three localities, information regarding which is given in the table of sec-

tions of coal beds in western Wyoming and eastern Idaho, on pages 73-75. Development work at one of these localities, the Miller mine, was begun in 1900 by the Canyon Coal Mining Development Co., which constructed a shaft, tunnel, road, buildings, and machinery at a cost reported at \$6,000. In 1910 Mr. Miller, one of the members of the former company, filed application to purchase and was permitted to make payment of \$1,600 for 160 acres of coal land at \$10 an acre. Work was continued, and a shaft 40 feet deep and engine house and hoisting machinery were installed at an additional cost of about \$2,500. The amount of coal that has been mined at this place was not determined. The area in which coal beds may be encountered by further prospecting is indicated in figure 7. For a further description of the geology of this part of Idaho the reader is referred to the paper by Schultz and Richards¹ already cited.

PINE CREEK AND GREYS RIVER AREA.

The coal in the belt extending from Pine Creek to Greys River occurs either in the Bear River or the Frontier formation and lies in the area between the Absaroka and Darby faults. The structure is complex, and the coal-bearing beds may not be present everywhere from the north to the south end of the belt. The Frontier formation east of the Absaroka fault has been traced from the vicinity of Hilliard, central Uinta County, Wyo., northward to Snake River, a distance of approximately 150 miles, and throughout this area the formation is coal bearing.²

The same belt of Cretaceous rock is believed to extend northward to the headwaters of Pine Creek, near the north end of the Snake River Range. The Frontier formation is known to be present between the Salt River and Wyoming ranges on Greys River and Little Greys River, south of Snake River, and may be present between the Bighole and Snake River ranges on the divide in Tps. 2 and 3 N., Rs. 44 and 45 E.; where the road crosses from Teton Basin to Swan Valley. The coal beds on the divide strike N. 60° W. and dip 70° SW. They resemble more nearly the Bear River than the Frontier coals. At this locality several prospects have been opened and considerable development work completed. It is reported that in T. 3 N., R. 44 E., \$4,000 has been expended on improvements, in opening drifts and doing assessment work, in an effort to open the coal.

In the southern part of Lincoln County, Wyo., the Frontier formation and other Cretaceous rocks lie in a synclinal basin immediately east of the Absaroka fault. In places farther north the west limb of the syncline has been cut out by the overthrust fault. In the vicin-

¹ U. S. Geol. Survey Bull. 530, pp. 267-284, 1912.

² U. S. Geol. Survey Bull. 316, pp. 212-241, 1907; Bull. 543, 1914.

ity of Snake River (see fig. 6, p. 48) the structure of the beds between the Darby and Absaroka faults is much more complex, and the Frontier formation occurs in a syncline immediately west of the Wyoming Range and reappears on the west side of a parallel anticline east of the Absaroka fault. Similar structural conditions may be expected between the Absaroka and Darby faults north of Snake River. Some of the evidence obtained indicates that the anticline and syncline observed on Greys, Little Greys, and Snake rivers extends throughout much of the northern area. However, until more detailed work has been done and the coal beds have been traced along the strike of the formation, it is impossible to state how much of the area between the two thrust faults is underlain by coal. The beds are in places closely folded and broken by faults. The available coal data obtained in this part of the field, although meager, are given in the table of coal sections on pages 73-75.

TETON BASIN AND McDOUGAL AREA.

The coal observed in the area extending from Teton Basin, Idaho, to McDougal Gap, Wyo., occurs for the most part in the Frontier formation in a narrow belt along the east side of the Bighole Mountains and Wyoming Range. The only locality at which coals of Evanston age may possibly be found in this area is in the vicinity of Snake River south of Cheney, Wyo., but as the structure and age of the beds in that locality have not been definitely determined the coal may be part of the Frontier or some other coal-bearing formation. Most of the coal beds in this area lie immediately east of the Darby fault and terminate against it. In places, however, the coal beds lie in a syncline some distance east of the fault, which in these places is in contact with pre-Cretaceous sediments. The structure is somewhat complex east of the Darby fault, just as it is west of the fault, and the coal beds may not be present everywhere along the east side of the mountains. The Frontier formation has been traced from the north end of Thompson Plateau, in T. 29 N., R. 115 W., northwestward to Snake River in T. 39 N., R. 116 W., a distance of 60 miles. Throughout the greater part of this distance the formation dips toward the fault, which brings the coal beds into contact with the older beds west of it. In the vicinity of Snake River the structure is more complex and the coal beds lie some distance east of the fault, as explained above. A more complete description of the geology and the occurrence of coal in the belt south of Snake River is given in Survey Bulletins 316 and 543.

The same belt of Cretaceous rocks occurs northwest of Snake River and is believed to be coal bearing where present throughout most of the area to the north end of the Bighole Mountains. Near the south end of the Teton Mountains the rocks are closely folded, and most if

not all of the Cretaceous beds have been removed by erosion. In that part of the range between station 39 and Trail Creek, or in the west flank of the Teton Mountains, the coal-bearing beds are believed to be absent, but farther northwest they occur in the same relation to the Bighole Mountains and the Darby fault as in the vicinity of Snake River and southward in western Wyoming along the east side of the Wyoming Range.

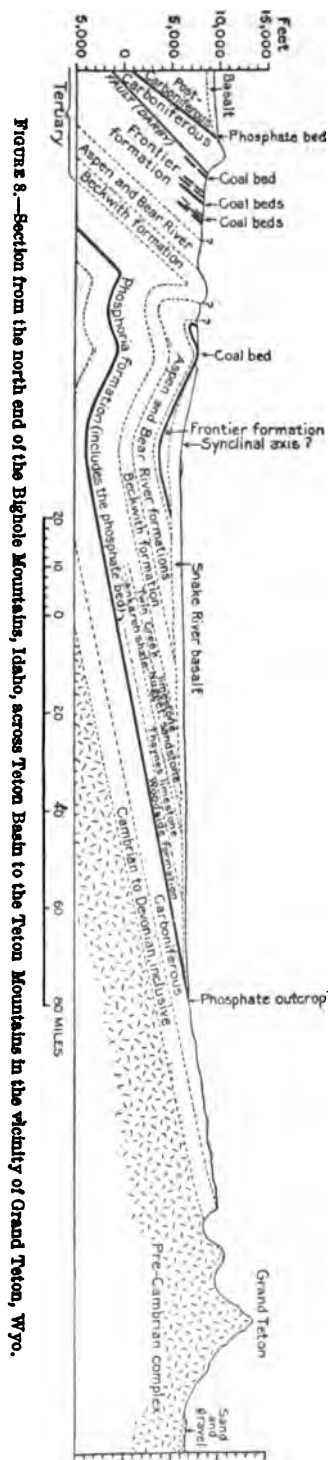
On the east bank of Snake River near the center of sec. 34, T. 40 N., R. 116 W., coal-bearing beds that are apparently conformable below the Almy formation were observed. Whether these coals belong to the Evanston, Frontier, or Bear River formation was not determined. They were examined hurriedly at only one locality, where they afford obscure plant remains that, together with their lithology and relation to the overlying conglomerates, afford a basis for their tentative correlation with the Evanston formation. If there is an unconformity between these beds and the gray calcareous conglomerate of the overlying Almy formation it is not apparent at this locality.

At the north end of the Bighole Mountains, along the east side of the thrust fault, the Frontier coals occur in at least two areas and probably underlie a large part of the valley lands of Teton Basin. Coals in this part of the Teton Basin coal field have been found and prospected from Mahogany Creek, in T. 4 N., R. 44 E., northward to Packsaddle Creek, in T. 5 N., R. 43 E., where the coal-bearing formation passes beneath the Tertiary lavas. The westernmost coal area in this part of the field lies immediately east of the Darby fault. The coal beds strike N. 40° W. and dip 45°-60° SW. The coal-bearing series has been traced for a distance of approximately 4 miles, and the continuity of the coals throughout this district has been demonstrated. Immediately east of this coal area is a prominent ridge of Jurassic beds that separates the coal-bearing rocks on the west from those on the east, as shown in figure 8. East of the Jurassic ridge only a few exposures of the coal-bearing beds were observed, and at only three localities have the beds been prospected. Coal has not been found exposed anywhere in the main part of Teton Basin east of the foothills of the Bighole Mountains, as the underlying rocks are within a short distance concealed by the Tertiary lava and Quaternary alluvium.

From a general study of the mountains surrounding the basin it is apparent that the structure is synclinal and that the basin may consist in part of Cretaceous strata that contain coal, concealed by the lava and alluvium. It has been reported that in a well drilled in 1903 on the old Breckenridge ranch, in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 35, T. 6 N., R. 44 E., west of Haden, a 10-foot bed of coal was penetrated at a depth of 650 feet. A sample of the coal obtained from the drill cutting yielded

48.7 per cent fixed carbon.¹ The coal, if present as reported, probably belongs to the Frontier formation and is the same as that observed in western Wyoming and along the east flank of the Bighole Mountains. If the structure in Teton Basin is correctly interpreted and the beds lie in a broad, open syncline, coal similar to that observed along the Bighole Mountains probably occurs at comparatively shallow depths ranging from a few feet along the west margin of the syncline to approximately 3,000 feet along the lowest part of the syncline. The axis of the concealed syncline probably lies in the vicinity of Victor, Idaho, and extends northward approximately halfway between Canyon Creek and the Victor branch of the Oregon Short Line Railroad to the north margin of the area mapped in T. 7 N., R. 43 E. The supposed structure of this part of Teton Basin is shown in the accompanying section (fig. 8). The syncline above referred to lies immediately northeast of the anticline observed at the south end of the Teton Mountains, in the vicinity of station 43, and in the Bighole Mountains east of the Darby fault, in the vicinity of station 41. Whether these two anticlines represent the same anticlinal fold was not determined, as the beds were not traced from one locality to the other. If the Frontier beds were eroded along the axis of the syncline before the lava was forced over the surface no commercial coal will be found in the synclinal basin. The presence or absence of coal in this part of the field can best be determined by means of the drill.

Coal beds of Frontier age occur immediately east of the Jurassic ridge



¹ Bell, R. N., Idaho State Insp. Mines Rept., 1903, p. 65.

that crosses secs. 19, 30, and 32, T. 5 N., R. 44 E., in a southeasterly direction. Very little is known regarding the distribution of the coals in this locality, as the sedimentary beds are largely covered by Tertiary lavas. On Horseshoe Creek, between lava-covered hills to the north and débris-strewn hills to the south, the beds have been opened at three localities in the SW. $\frac{1}{4}$ sec. 28. One of the prospects lies north of the creek and another immediately south of it; the third is south of the wagon road that leads from Teton Basin to the Boise and Brown Bear mines. These prospects were the first to be opened in this vicinity. The property is locally known as the old Flann mine and was first opened in 1882 by Henry Flann, a prominent merchant of Rexburg, Idaho, who abandoned the enterprise before developing it into a producing mine. Later the Idaho Fuel Co. further prospected the coal at this locality and opened three drifts. Two beds of coal occur, ranging in thickness from 20 inches to 4 feet. They strike north and dip 10° W. The drift on the south side of the creek, according to report, was driven for 150 feet, and the one on the north for 100 feet. The prospect opening south of the road was driven down the dip. The extent of the coal encountered and the length of the slope were not determined, as the opening is now caved and the coal in part concealed. A thickness of 2 feet of coal was measured above the caved débris. The size of the dumps at these three prospects indicates that considerable work has been done and some coal taken out.

Similar coals are reported to occur farther south, on Mahogany Creek, but these were not visited. About half a mile east of the prospects on Horseshoe Creek lava caps the hills and forms the mountain slopes on both sides of the creek and covers gentle slopes out into Teton Basin. The area in which coal-bearing rocks are exposed is therefore small and confined chiefly to the valley of Horseshoe Creek and its tributaries, although the same beds may crop out on Mahogany Creek and other small streams toward the southeast.

West of the Jurassic ridge coal has been traced from Horseshoe Creek north to Packsaddle Creek. This area, examined by the writer in a cursory way, was studied in more detail in the fall of 1912 by E. G. Woodruff,¹ who spent several days in mapping the coal beds in this vicinity, collecting data so that the coal lands could be appraised and classified. Some of the data on this area here presented were obtained from him. Woodruff found that only a small part of the area contains coal beds which the miners in the field considered thick enough to work in 1912. The coal lands in this part of the field range in value from \$20 to \$58 an acre. The coal beds crop out along the slope near the foot of the escarpment and dip toward the over-

¹ Woodruff, E. G., The Horseshoe Creek district of the Teton Basin coal field, Fremont County, Idaho: U. S. Geol. Survey Bull. 541, pp. 379-388, 1914.

thrust fault. The beds are cut also by numerous small faults, as is well shown in the Brown Bear mine, where seven faults cut the coal bed in a distance of approximately 1,200 feet. The rock and coal outcrops are badly caved, so that it is difficult to trace them for any considerable distance without the aid of a drill. The coal prospects that have been opened on Horseshoe and Packsaddle creeks, according to report, disclose seven separate coal beds that range in thickness from 2 to 10 feet and are comparatively free from bony coal or waste material. The most extensive development work has been done on the Brown Bear, Boise, Horseshoe, and Packsaddle mines, although considerable prospecting has been done at several other places in the district. These four properties cover the strike of the coal-bearing rocks for a distance of 3 miles, throughout which the continuity of the coals has been fairly well proved. Only the Brown Bear and Boise were producing mines at the time of the writer's visit. Mining and prospecting had been carried on, however, at other places in the field, but the work had apparently been discontinued.

The Brown Bear mine is the chief producer in the field and has been operated since 1904. The mine consists of a horizontal rock tunnel, 325 feet long from the surface to the coal bed, and two horizontal entries, one to the north 950 feet long and the other to the south 250 feet long, both following the strike of the bed, which is N. 40° W. The bed ranges in thickness from 4 feet 5 inches at the north end to 5 feet 3 inches at the south end and dips 40°-50° SW. The mine is worked by the room and pillar method. The rooms are turned up the pitch along a drift or entry at 60-foot intervals, center to center. The center of the room is driven ahead, and the coal is undermined with a pick along a softer layer, 1 inch to 16 inches thick, that lies on the floor of the mine, and blasted down with a back hole and a small charge of black powder. The broken coal slides down a chute at the narrow outlet of the room and is hauled to the entry. The mine is well ventilated by raises to the surface and cross courses through the pillars. A good deal of the coal produced in 1912 was sold at the mine as mine run for \$2.50 a ton. Some of it was screened and sold for \$3.50, and the slack was sold for 50 cents a ton.

The Boise mine was not selling coal at the time of the writer's examination, but arrangements had been made to mine a few tons daily for use in Teton Basin. The coal bed here is 38 inches thick, is entirely free from bone and waste of any kind, and lies between beds of shale. The mine consists of a rock tunnel 150 feet long, that crosscuts the strata, and an entry 200 feet along the bed from the point where the tunnel enters the coal. The mine was opened in 1904 and has been supplying some excellent coal at irregular intervals since that time.

The Horseshoe mine is near the southeast corner of the NW. $\frac{1}{4}$ NW, $\frac{1}{4}$ sec. 6, T. 4 N., R. 44 E., and was opened by the Horseshoe Coal Co. prior to 1902. The bed is approximately 10 feet thick and dips 66° SW. The small dump at the mouth of the mine indicates the extent of the workings and represents the waste taken out in mining. The development work consists of a single entry, 500 feet long, extending north into the side of a steep hill where the bed was exposed. Although badly caved the mine can be entered for a distance of 200 feet or more, and good sections of the bed measured. Several thousand tons of coal was extracted and sold at the mine for \$2 a ton. The mine was poorly developed, and this in part furnishes an explanation why the work at this locality soon became dangerous and the prospect was abandoned.

The Packsaddle mine lies in the NE. $\frac{1}{4}$ sec. 26 and the NW. $\frac{1}{4}$ sec. 25, T. 5 N., R. 43 E. There are two openings at this place, both of which are badly caved, so that it was impossible to determine the relations of the workings in the lower one to those in the upper one. The dump at the mouth of the mine contains some good coal, and the general improvements, including a Victor standard scale, mine buildings, miners' cabin, and coal road, indicate that considerable work was done here and some coal mined. No coal is exposed in the mouth of the lower entry, the small sticks or poles used in timbering are broken, and the entrance to the coal bed is cut off by caved ground, so that no data as to the character or thickness of the coal were obtained. Some coal has also been taken from the upper drift. This entry likewise was badly caved, but coal exposed at its mouth indicates that the bed is more than 2 feet 3 inches thick—no doubt much more, as the caved material conceals the lower part of the bed. The entire bed is reported to be 9 feet thick and to terminate against a fault. The mine was opened in 1906, and work was continued for a year or more before the property was abandoned. On the ridge just south of the abandoned mine the gray sandstone strikes N. 20° W. and dips 50° SW.

SECTIONS OF THE COAL BEDS.

The location of the prospect pits which were examined during this survey or from which reports have been obtained and the sections of coal beds exposed in them are given in the following table. The mines, prospect pits, surface diggings, and coal exposures are numbered consecutively from 1 to 37, beginning at the southeast corner of the field, and the numbers agree with those used on Plate I. Nos. 1 to 10 are in Wyoming and Nos. 11 to 37 in Idaho.

Sections of coal beds in eastern Idaho and western Wyoming.

Wyoming.

No. on Plate I.	Location.			Formation.	Section of coal.	Analyds. No.	Remarks.
	T.	R.	Sec.				
1	36 N.	117 W.	18, SW. 1/4	Frontier	Coal..... Ft. in. 3	4323	Surface prospect west of Greys River. Coal slightly weathered.
2	37 N.	116 W.	1, SW. 1/4 SE. 1/4	Frontier	Coal..... 3 6	4302	Surface prospect; lower 15 inches dirty; upper 2 feet clean. Bed lies about 40 feet lower than No. 3.
3	37 N.	116 W.	1, SW. 1/4 SE. 1/4	Frontier	Coal..... 3 9	4301	Bed has a 7-inch parting and lies about 40 feet above No. 2. Surface prospect.
4	37 N.	116 W.	1, NW. 1/4 SE. 1/4	Frontier	Coal..... 4 6	.....	Surface prospect.
5	37 N.	116 W.	1, NW. 1/4 SE. 1/4	Frontier	Coal..... 7 6	.....	Two prospects opened by G. B. Budd.
6	37 N.	116 W.	1, W. 1/4 SE. 1/4	Frontier	Coal..... 20	.....	Surface prospect.
7	37 N.	116 W.	1, SW. 1/4 SE. 1/4	Frontier	Coal and bone..... 1 6 Clay, white..... 1 6 Coal..... 3 Clay..... 1 Coal..... 1	4003	Surface prospect. Coal slightly weathered.
8	38 N.	116 W.	11, NW. 1/4 SW. 1/4	Frontier	Coal..... 2 3	.....	Surface prospect. Coal dips 5° E.
9	39 N.	116 W.	27, SW. 1/4 SW. 1/4	Frontier (?)	Coal (?).	.....	Coal indications reported on General Land Office township plat.
10	40 N.	116 W.	34, SW. 1/4 NE. 1/4	(?)	Shale. Coal..... 1 5 Clay.	4002	Probably same as Eyanston (?) coal beds surface prospect along bank of Snake River. Coal badly weathered.

a Bed sampled.

COAL.

Sections of coal beds in eastern Idaho and western Wyoming—Continued.
Idaho.

No. on Plate I.	Location.			Formation.	Section of coal.	Analysis No.	Remarks.
	T.	R.	Sec.				
11	1 S.	40 E.	24, SE. $\frac{1}{4}$ SE. $\frac{1}{4}$	Bear River or Frontier (?)	Coal (?).	.....	Croley mine. General Land Office plat shows coal tunnel.
12	1 N.	42 E.	20.....	Bear River or Frontier (?)	Coal.....	47	Fall Creek basin. Prospect in which good grade of coal occurs.
13	2 N.	40 E.	34, SE. $\frac{1}{4}$ NE. $\frac{1}{4}$; NE. $\frac{1}{4}$ SE. $\frac{1}{4}$; 40 SW. $\frac{1}{4}$ NW. $\frac{1}{4}$; NW. $\frac{1}{4}$ SW. $\frac{1}{4}$	Bear River or Frontier (?)	Coal.....	3 67	John Miller mine. Shaft 40 feet deep. Some coal mined.
14	3 N.	44 E.	24.....	Bear River or Frontier.	Coal.....	2 4	Surface prospect. Opened by Pine Creek Coal Co., June 26, 1912.
15	3 N.	45 E.	19.....	Bear River or Frontier.	Coal.....	4	Surface prospect. Opened by Pine Creek Coal Co. Reported 4-foot bed.
16	4 N.	44 E.	35, SE. $\frac{1}{4}$ SW. $\frac{1}{4}$	(?)	Coal (?).	.....	Coal indications reported on General Land Office township plat, 1910.
17	4 N.	44 E.	19, SW. $\frac{1}{4}$ SW. $\frac{1}{4}$	(?)	Coal (?).	.....	Coal indications reported on General Land Office township plat, 1910.
18	4 N.	43 E.	19, SW. $\frac{1}{4}$	(?)	Coal (?).	.....	Coal indications reported on General Land Office township plat, 1910.
19	4 N.	43 E.	2, SE. $\frac{1}{4}$ SW. $\frac{1}{4}$	(?)	Coal (?).	.....	Coal indications reported on General Land Office township plat, 1910.
20	5 N.	44 E.	28, SW. $\frac{1}{4}$	Frontier.....	Coal.....	2+	Entry driven down dip. Entrance caved.
21	5 N.	44 E.	28, SW. $\frac{1}{4}$	Frontier.....	Coal.....	$\left\{ \begin{array}{l} 1 \\ \text{to } 4 \end{array} \right. 8$	Prospect entry reported to be driven 100 feet.
22	5 N.	44 E.	28, SW. $\frac{1}{4}$	Frontier.....	Coal.....	$\left\{ \begin{array}{l} 1 \\ \text{to } 4 \end{array} \right. 8$	Prospect entry reported to be driven 150 feet.
23	5 N.	44 E.	32, NW. $\frac{1}{4}$	(?).....	Reported coal blossom	4	Prospect pit 10 feet deep. Not in Frontier formation.

COAL.

75

24	4 N.	44 E.	6, NW. $\frac{1}{2}$ NW. $\frac{1}{2}$	Frontier.....	Coal a..... 1 11 Sandstone..... 10 Coal a..... 3 4 Coal, bony..... 1 9 Coal, crumbed a..... 3 3	15110	Horrecho mine. Single entry 500 feet long. Section measured 200 feet from mouth of entry.
25	4 N.	44 E.	6, NW. $\frac{1}{2}$ NW. $\frac{1}{2}$	Frontier.....	Coal..... 2 2	.....	Abandoned entry 80 feet long. Same bed as No. 26.
26	4 N.	43 E.	1, SE. $\frac{1}{2}$ NE. $\frac{1}{2}$	Frontier.....	Coal..... 3	.....	Surface prospect. Opened on same bed as No. 25.
27	4 N.	43 E.	1, SE. $\frac{1}{2}$ NW. $\frac{1}{2}$	Frontier.....	Coal fragments.....	.....	Small prospect in dump material contains fragments of coal
28	5 N.	44 E.	31, SW. $\frac{1}{2}$ SW. $\frac{1}{2}$	Frontier.....	Shale..... 2 Coal..... 3 8 Shale..... 1 10 Coal..... 4 3 Shale..... 4 4	.....	Surface prospect. Probably same bed as that opened at Nos. 24 and 26.
29	5 N.	43 E.	25, SE. $\frac{1}{2}$ SE. $\frac{1}{2}$	Frontier.....	Coal..... 5 \pm	15115	Brown Bear mine. Horizontal rock tunnel 325 feet; 1,200 feet drift.
30	5 N.	43 E.	25, SE. $\frac{1}{2}$ SW. $\frac{1}{2}$	Frontier.....	Coal..... 3 2	.....	Boise mine. Rock tunnel 150 feet. Coal entry 200 feet.
31	5 N.	43 E.	25, NW. $\frac{1}{2}$ NW. $\frac{1}{2}$	Frontier.....	Coal on dump; bed not seen.	.....	Lower opening at Packsaddle mine. Entry caved.
32	5 N.	43 E.	26, NE. $\frac{1}{2}$ NE. $\frac{1}{2}$	Frontier.....	Shale..... 2 Coal..... 2 3	.....	Upper opening at Packsaddle mine. Entry caved.
33	5 N.	43 E.	24, SE. $\frac{1}{2}$ SE. $\frac{1}{2}$	Frontier.....	Coal..... 3 4	.....	Surface prospect.
34	5 N.	43 E.	24, SE. $\frac{1}{2}$ SE. $\frac{1}{2}$	Frontier.....	Coal..... 1 1	.....	Surface prospect.
35	5 N.	43 E.	24, SE. $\frac{1}{2}$ SE. $\frac{1}{2}$	Frontier.....	Coal..... 8 Coal, bony..... 3 Coal..... 8	.....	Surface prospect.
36	5 N.	43 E.	24, SE. $\frac{1}{2}$ SE. $\frac{1}{2}$	Frontier.....	Coal..... 3 4	.....	Abandoned entry. Bed appears to be badly crumbed.
37	5 N.	43 E.	24, SW. $\frac{1}{2}$ SW. $\frac{1}{2}$	Frontier.....	Coal..... 1 7 Shale..... 10 Coal..... 1 1	.....	Prospect pit 6 feet deep.

a Bed sampled.

CHARACTER OF THE COAL.

The coal is bituminous and rather free from impurities. According to report some of it has been coked with fair success. However, the tests made in an agate mortar gave noncoking results. Most of the coal is badly shattered, as would be expected in a region where so much faulting has taken place. As a result of this shattered condition a large percentage of the coal in mining comes out fine. Even the larger pieces are so broken that they do not readily stand handling, and much of it is necessarily marketed as slack. The present market for the coal produced in this field is largely confined to the settlers who live within hauling distance of the mine. The coal is extensively used by the farmers to run their steam engines during the plowing, seeding, and harvesting seasons, and by the thrasher and header crews. In 1912 it sold at the mine for \$3.50 a ton for lump coal, \$2.50 for run-of-mine, \$2 for the small sizes, and 50 cents for slack. A good deal of the lump coal is hauled to St. Anthony and other railroad settlements, where it generally commands \$1 a ton more than the coal that is shipped in from the Mississippi Valley region, as it is apparently much better, has a higher heating value, and contains less ash.

Samples of coal from the Frontier formation have been collected for analysis from several localities in this region and the results are given in the following table. The sampling was done according to the regulations of the United States Geological Survey, which require that the sampled face must be cleared of weathered coal, powder stains, and surface impurities. A channel is then cut across the bed to obtain the sample, and at the same time large partings or lumps of impurities are rejected. The sample is collected on a sampling cloth, then broken up to pass through a $\frac{1}{4}$ -inch mesh sieve, mixed thoroughly, quartered, and mixed again, and finally the sample is placed in a sealed can to be forwarded to the chemical laboratory.

Analyses of coal samples from Frontier formation of eastern Idaho and western Wyoming.
 [First five analyses made at United States Geological Survey fuel-testing laboratory; F. M. Stanton, chemist in charge. Last two analyses made at the Pittsburgh laboratory of the Bureau of Mines; A. C. Fletcher, chemist in charge.]

No. on Plate I.	Location.	Laboratory No.	Air-drying loss.	Form of analysis.	Chemical analyses.										Heat value.	
					Proximate.					Ultimate.						
					Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific.	British thermal units.	
1	Greys River, SW. $\frac{1}{2}$ sec. 18, T. 36 N., R. 117 W..	4323	3.6	A B C D	7.8 4.4	36.3 37.6 39.3 40.0	54.3 56.3 58.9 60.0	1.63 1.68 1.76	0.37 .28 .29 .30	5.35 5.14 4.86 4.95	70.34 72.97 76.29 77.66	1.43 1.48 1.55 1.58	20.99 18.45 15.25 15.51	7,095 7,360 7,665 7,880	12,770 13,260 13,860 14,100	
2	Wyoming Range, SE. $\frac{1}{2}$ sec. 1, T. 37 N., R. 116 W.	4302	2.3	A B C D	6.8 4.6	33.4 34.2 35.9 38.4	53.6 54.9 57.5 61.6	6.18 6.33 6.63.....	.63 .64 .67 .71	4.81 4.65 4.35 4.65	66.45 71.09 74.52 76.82	1.52 1.55 1.63 1.75	17.42 15.74 12.20 13.07	6,750 6,910 7,245 7,760	12,160 12,440 13,040 13,970
3	Wyoming Range, SE. $\frac{1}{2}$ sec. 1, T. 37 N., R. 116 W.	4301	6.0	A B C D	10.7 5.0	30.7 32.6 34.3 36.1	54.3 57.8 60.9 63.9	4.28 4.55 4.79.....	.78 .63 4.79 .92	5.34 4.98 4.65 4.88	66.18 70.41 74.11 77.84	1.45 1.54 1.62 1.71	21.97 17.70 13.96 14.65	6,355 6,765 7,120 7,475	11,440 12,170 12,810 13,460
7	Wyoming Range, SE. $\frac{1}{2}$ sec. 1, T. 37 N., R. 116 W.	4003	4.6	A B C D	10.1 5.7	32.9 34.5 36.6 38.2	53.3 55.9 59.3 61.8	3.70 3.88 4.11.....	.38 .40 .43 .44	5.27 4.98 4.61 4.81	66.94 70.17 74.43 77.62	1.29 1.35 1.43 1.50	22.42 19.23 15.00 15.63	6,465 6,775 7,185 7,495	11,640 12,200 12,940 13,480
10	Snake River, NE. $\frac{1}{2}$ sec. 34, T. 40 N., R. 116 W..	4002	7.9	A B C D	18.3 11.2	23.2 25.2 28.3 40.2	34.4 37.4 42.2 59.8	24.08 26.16 28.48.....	.30 .33 .37 .63	4.12 3.51 3.55 3.62	42.08 45.63 51.42 72.92	.57 .62 .70 .99	28.90 23.75 15.48 21.95	3,695 4,010 4,520 6,405	6,650 7,220 8,130 11,530
29	Brown Bear mine, SE. $\frac{1}{2}$ sec. 25, T. 5 N., R. 43 E..	15115	8.3	A B C D	11.5 3.4	37.2 40.6 42.0 44.2	47.0 51.3 53.1 55.8	4.30 4.69 4.86.....	.64 .69 .61 .64	5.94 5.47 5.27 5.54	68.09 74.25 76.89 80.82	1.40 1.53 1.58 1.66	19.73 13.47 10.79 11.34	6,720 7,325 7,590 7,975	12,000 13,190 13,660 14,360
24	Horseshoe mine, NW. $\frac{1}{2}$ sec. 6, T. 4 N., R. 44 E..	15116	4.3	A B C D	7.7 3.6	39.7 41.5 43.0 44.1	50.4 52.6 54.6 55.9	2.2 2.3 2.4.....	.38 .40 .41 .42	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	..... ..... ..... .....	7,155 7,475 7,765 7,945	12,880 13,460 13,960 14,300

* A, Coal as obtained in the mine; B, coal dried at a temperature of 30° to 35° C.; C, moisture-free coal; D, coal free from moisture and ash.

Sample 4323 was collected from a shallow prospect on the west side of Greys River a few miles south of the mouth of Little Greys River, in what is known as the Greys River coal field. The sample was taken a few feet below the surface and represents a coal of good quality, which nevertheless may have been partly altered by weathering.

Sample 4302 was collected from a prospect pit in the Wyoming Range that had been exposed to the atmosphere for more than a year, and as a result the coal had no doubt been considerably altered. The lower part of the 3 feet 6 inch coal bed is composed largely of bone, but the upper 2 feet, which was sampled, is a good clean coal. The sample was taken 40 feet stratigraphically below sample 4301.

Sample 4301, from a shallow prospect in the Wyoming Range, represents a coal bed 3 feet 9 inches thick which was moderately weathered. The sample as collected does not include a 7-inch parting that is present in the bed at this point. The coal bed lies approximately 40 feet stratigraphically above sample 4302, and the coal is of the same quality.

Sample 4003 was collected from a surface prospect in the Wyoming Range, in which the coal bed clearly shows the effects of weathering. The 3-foot bench of coal that lies near the middle of the measured section (see table, p. 77) is the only part of the bed included in the sample.

Sample 4002 was taken from a cut in a coal bank on Snake River, where 1 foot 5 inches of coal was exposed. It represents a surface outcrop in which the coal was so greatly altered by weathering that the sample does not fairly represent the quality of the coal.

Sample 15115, collected by E. G. Woodruff in 1912 from the Brown Bear mine, in the Bighole Mountains, was taken from the end of the north entry, 950 feet from the portal, where mining had been done recently and where the coal was unweathered. This sample is believed to represent the coal in its normal condition as taken from the mine.

Sample 15116, collected by E. G. Woodruff in October, 1912, from the abandoned Horseshoe mine in the Bighole Mountains, was moderately weathered. It was taken at a point 200 feet from the portal from a face that had been exposed for more than a year. The surface of the bed was cleaned until apparently fresh coal was obtained, but it seemed probable that some change which had not altered the physical appearance of the coal may have taken place, because the mine is in a fairly dry climate and had remained open to the unrestricted circulation of the air for a long time. Nevertheless, the sample gave a higher calorific value than the unweathered coal from the Brown Bear mine. This result is probably to be explained in



A. BURLAP TABLES ARRANGED FOR SAVING FINE GOLD NEAR THE MOUTH OF McCOY CREEK ON SNAKE RIVER, IDAHO.



B. PUBLIC SCHOOL BUILDING AT IRWIN, IDAHO, CONSTRUCTED OF RHYOLITE BLOCKS QUARRIED IN THE VICINITY.

Baldy Mountain, a part of the Snake River Range, in the background.



C. AURIFEROUS GRAVELS AND ALLUVIUM CARRYING FINE FLAKES OF GOLD.

Note large pebbles along sluicing ditch from which finer material has been washed.

part by the smaller amount of ash in the Horseshoe sample and the fact that very little alteration had taken place in the coal bed during its exposure to the circulation of the air.

GOLD AND OTHER MINERALS.

Placer mining has been done along Snake River and its tributaries since 1860. The gold on these streams occurs in the gravels that form terraces along the streams and in the deposits of boulders, gravel, and sand that fill the channels or form the beds of the streams. A small placer working was observed on Snake River just below the mouth of Wolf Creek. At the time of visit the work had been discontinued for the winter, and no details regarding the gravels were obtained. The deposits along Snake River are more fully described in Survey Bulletins 315, 530, and 543. There are no metalliferous mines in this region, and only a little desultory prospecting is carried on. Most of it has been done in pre-Cambrian rocks in the Teton Mountains, where a little lead, silver, and copper have been reported. Structural material, lime, cement, clay, and road dressing may be obtained in many localities. Excellent building stone is obtained from the Tertiary rhyolite, which has been extensively used for public buildings and private dwellings in certain parts of the area. The rock is soft enough to be easily quarried and firm enough to be dressed to any desired shape. (See Pl. II.)

Reports of occurrences of oil in eastern Idaho have been received from time to time. If the anticline along the west side of Teton Basin has a closed structure, there may be oil in this part of the field. An oil well was drilled in 1903 some distance east of the syndinal axis that passes through the basin. The following statement regarding this well was furnished in the fall of 1906 by Mr. Spencer Clawson, 131 South Main Street, Salt Lake City, Utah:

The president of the Fremont County Oil, Gas & Coal Co., W. E. McDonald, a native of the oil section of eastern Indiana and later of Florence, Colo., visited the Teton Valley in 1900 with a view, it is said, of purchasing a ranch; he negotiated with me for 800 acres of land at the crossing of Teton River near Hayden and made a payment upon it; later he called and stated that there were very strong surface indications of the presence of oil on the land, his long residence in the Indiana and Colorado oil fields qualifying him to judge.

I paid but little attention to the man or his enterprises, and he returned to his former home in Colorado, organized the Fremont County Oil, Gas & Coal Co., and vigorously prosecuted the work of boring for oil on the ranch of David Breckenridge, which joined the lands Mr. McDonald had purchased from me on either side; his difficulties were great, as it was about 30 miles to Rexburg or St. Anthony, the nearest railroad point, and transportation of engine, boiler, pipe, etc., was both difficult and expensive; but he was a man of perseverance, though of moderate resources, and he expended the capital of the company, some \$6,000, before he found anything that indicated values. His enthusiasm was unbounded, and through great effort he procured more money and continued his work.

In the fall of 1903 his 8-inch drill struck a seam of coal at a depth of about 650 feet, and he told me that he had driven 10 feet into the seam without reaching the foot-wall; he then withdrew his drills in order to sink the 10-inch pipe casing.

The supply of pipe being exhausted, he suspended operations and returned to Colorado for more material and money. On his way east he stopped at Salt Lake City and urged me to join him in his efforts to develop the coal and oil, which he asserted would be struck at greater depth.

As he failed to make the second payment on the purchase price of the land, I was unable to render him the financial aid he desired. I never saw Mr. McDonald again, but subsequently learned that he was taken ill in Florence, Colo., and after a brief illness died in a hospital there.

The enterprise was abandoned by his administrators; his creditors removed the engine, boiler, drills, etc., leaving only the derrick and the 10-inch pipe casing in the well. The land was sold by the sheriff and was purchased by me for the interests that formerly owned it.

Another source of oil that promises to be of some value occurs at the same horizon as the phosphate deposits in Montana, Idaho, and Wyoming—that is, in the Phosphoria formation. The phosphate on applying heat to the rock is not driven off by distillation but remains in the ash. Evidence of petroleum or bituminous compounds in rocks of this age has been observed over wide areas by the writer, who has worked on the phosphate deposits, but few, if any, tests have heretofore been made to ascertain the quantity of oil. Small remnants of samples of phosphate rock, E, G, H, I, and X, collected in Idaho and western Wyoming for phosphate determinations, were also tested for oil.

Tests of phosphate rock containing oil in eastern Idaho and western Wyoming.

[Chase Palmer, U. S. Geological Survey, and C. S. Reeve, Office of Public Roads and Rural Engineering, analysts.]

No.	Location.	Laboratory No. (Office of Public Roads and Rural Engineering.)	Phosphorus pentoxide (P_2O_5).	Tricalcium phosphate ($Ca_3(PO_4)_2$).	Specific gravity.	Petroleum.		
						Dry distillation (gallons per ton).	Carbon tetrachloride extraction.	Carbon disulphide extraction (per cent).
E....	Trail Creek, Wyo., NE. $\frac{1}{2}$ sec. 16, T. 41 N., R. 118 W.	12781	Trace.	Trace.	1.93	A little oil ^a .	Little.....	0.34
G....	Pallsade Creek, Idaho, sec. 25, T. 2 N., R. 45 E.	12782	12.69	27.8	2.33	Little oil distillate. ^a	Very little...	.79
H....	South Fork of Ramey Creek, Idaho, sec. 16, T. 2 N., R. 45 E.	12783	31.69	69.4	2.24	A little oil ^a.	.....do.....	.98
I....	North Fork of Ramey Creek, Idaho, sec. 8, T. 2 N., R. 45 E.	12784	17.08	37.4	2.64	.....do.....	.....do.....	1.19
X....	Young's ranch, southwest of Lander, Wyo., sec. 8, T. 31 N., R. 99 W.	12785	24.3	53.16	2.31	3.17.....	Some.....	4.89

^a Mr. Reeve omitted the dry distillation of these samples because so little material was submitted as to make it practically impossible to obtain results of any value.

The rocks in the region where the samples were obtained have been subjected to extreme pressure and affected by metamorphism, as shown by the faulting and squeezing manifested at many places and by the crystallization of the limestone. A considerable part of the organic matter that was originally in the rock may therefore have undergone partial distillation, a supposition that in turn may account for the relatively small quantity of oil obtained from these rocks. If the rocks in which the small quantities of oil are found have already undergone partial distillation, the question arises, What has become of the distillate? Where the rocks are exposed the oil has undoubtedly escaped, and this may account for the slight yield on extraction from rocks that give off a strong odor of petroleum. Where the rocks are not exposed they may have been a source of supply of petroleum in areas where the structural conditions are favorable to its accumulation. It may therefore be possible that commercial accumulations of oil have been formed in these older Paleozoic rocks. If this should be true, it would open up a new field for exploration in this part of the Rocky Mountain region. Thus far the Lander oil field in Wyoming seems to be the only place where oil has been obtained in commercial quantities from rocks of the same age, though indications of oil at this horizon have been noted at several other places in Wyoming and Utah.

WATER POWER.

This area affords one conspicuously good opportunity for developing large quantities of water power, near the mouth of the Snake River canyon. Throughout the remainder of the area there are numerous localities where small plants can be installed whenever suitable markets are developed. The creeks that flow from the Caribou, Snake River, Salt River, Bighole, Wyoming, and Teton mountains are all permanent, and in their canyons there are many places where dams can be built to advantage and small power of low head developed. There are, however, very few falls of any consequence and only a few localities, as in the canyon of Snake River and in the canyon of North Fork of Teton River, where considerable head may be obtained. Snake River is the only stream in which a large body of water is available.

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**THE OXIDIZED ZINC ORES OF LEADVILLE
COLORADO**

BY

G. F. LOUGHLIN



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THE OXIDIZED ZINC ORES OF LEADVILLE, COLORADO.

By G. F. LOUGHLIN.

INTRODUCTION.

Oxidized zinc ores were first exploited in the Leadville mining district, Colorado, after the Geological Survey's field study of the other ores had been completed. In the summer of 1913 the writer was detailed to study these ores and spent four weeks in the district during July and August. The present report was completed early in 1914 and transmitted to form a chapter in a monograph on the geology and ore deposits of the district, but owing to continued delay in the completion of the monograph it has been decided to publish this chapter in advance.

The mine operators and engineers in the district gave the writer all possible assistance in his work. Thanks are especially due to Messrs. Nicholson, MacDonald, and Dalrymple, of the Western Mining Co.; Messrs. Platt and Kleff, mine surveyors and lessees of the New Dome property; Messrs. Davis and Pendery, of the Yak Co.; Messrs. Argall and Aicher, of the Iron Silver Co.; the officers of the Ibex Co.; Mr. Warren F. Page, of the Luema Mining Co.; and Mr. John R. Curley, State inspector of mines. To the several other lessees, foremen, and miners who rendered assistance at different times the writer here expresses his hearty thanks. Thanks are also due to Mr. R. C. Wells, of the United States Geological Survey, for criticism of the discussion of chemical processes involved in the deposition of the oxidized zinc ores.

DISCOVERY.

After it was realized, in 1910, that large deposits of oxidized zinc ores were present in the Leadville district, considerable discussion arose over the fact that these ores had been so long overlooked both by the mining engineers and geologists who had made frequent visits to the mines and by the mine officers and assayers who had been working in the ore and handling samples of it for several years. It

must be admitted that the ore had been exposed both on dumps and underground and all who have had an opportunity of finding it must share the blame of having overlooked it. Very few of those who have written on the subject realized that silicate and carbonate of zinc had been known to exist from the earliest days, when only a comparatively small part of the oxidized lead ores had been worked.

EARLY ACCOUNTS OF ZINC CARBONATE AND SILICATE.

The following paragraph was published as long ago as 1882:¹

Mr. Garrison (of St. Louis) makes the prediction that at an early date Colorado will be made tributary to the western spelter industry. Probably the first call will be made for carbonates, calcined before shipping. This class of zinc ores often so closely resembles limestone that the ordinary prospector would not detect its value. If we remember correctly, Prof. König, of Philadelphia, has found calamine, or carbonate ore, in the vicinity of Leadville. Should a closer search, which we trust will be made at an early date, reveal the presence of larger bodies of this ore, zinc mining might soon be added to the list of Colorado industries.

It was thus early known, therefore, that oxidized zinc ores occurred in the Leadville district, but zinc was then evidently of insufficient interest to stimulate prospecting for bodies of high-grade zinc ore.

In 1886 Emmons, in his famous monograph,² noted the occurrence of calamine at Leadville and mentioned zinc blende and calamine as accessory minerals. He evidently had considered the problem of the disposition of the zinc in the oxidized zone, as he shows in his description of the old Iron mine:

In the body of the limestone, on the eighth level, not far from the north incline, a natural jointing plane forming one wall of the drift was observed to be coated with fine, silky white crystals which chemical examination proved to be calamine or silicate of zinc. If the sulphureted ores, which will undoubtedly be found when the mine workings shall have reached the limits of the zone of oxidization, are as rich in blende as those which have been found in the A. Y. mine, it seems singular that little or no zinc has hitherto been found associated with the oxidized ore. This occurrence would seem to show that, owing probably to greater solubility, the alteration products of blende have been removed during secondary deposition to a greater distance from their original location than those of the other sulphurets.

Again, he writes:

Zinc occurs in the lead carbonate ores in very small proportion and probably in the form of silicate (calamine), since this is the only mineral of zinc that has been observed in the Leadville deposits. It is rarely visible and generally form fine, needle-like silky-white crystals, lining drusy cavities and cracks or joints in vein material and limestone. There is little doubt that it originally occurred as zinc blende, and, from analogy with the Tenmile deposits, it may be presumed that it formed a much larger proportion of the deposit than it does

¹ Eng. and Min. Jour., vol. 34, p. 16, 1882.

² Emmons, S. F., Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey Mon. 12, pp. 376, 389, 398, 547, 550, 556, 557, 560, 1886.

now. The much greater solubility of its sulphate than that of the other metals would account for its more thorough removal by surface waters.

He noted the absence of zinc in analyses of samples of basic ferric sulphate, a feature in accordance with the observation, quoted above, that the zinc had been further removed from the original ore bodies than the other metals, owing to the more ready solubility of its sulphate, and he states that in spite of the comparative absence of zinc this metal was "quite uniformly detected in the products of smelting."

The analyses of different vein materials show little or no zinc. A siliceous hematite from the Chrysolite mine, carrying 2.56 per cent of zinc oxide, was said to contain "a rather unusual percentage of zinc." As these vein materials were in large part similar in color and other visible features to the reddish-brown zinc ores now mined, the absence in all of them of any considerable amount of zinc may well have diverted Emmons's attention, both then and in later years, from such iron-stained bodies as possible oxidized zinc ores. Very little drifting or other work beneath the old lead stopes had been done at the time, and no ground with abundant pockets of calamine, such as characterize much of the oxidized zinc ore now mined, had been exposed. Even after some of the extensive zinc ore bodies had been exposed along drifts and other workings the strong resemblance of the reddish-brown ore to iron ore at one extreme and iron-stained limestone at the other and the close resemblance of the gray ore to partly leached but unstained limestone were hardly likely to lead one to suspect the presence of high-grade zinc ore. These ores are in general so different in color and texture from the more crystalline and brilliant specimens from other districts, so common in museums and other collections, that failure to recognize them without chemical examination is not surprising.

Emmons, however, did recognize the rather exceptional occurrences of small quantities of the dense white zinc ore that is identical in appearance with "Chinese talc," as shown by his discussion of the analyses. He regarded this material as a mixture of hydrated silicates of alumina and silicate of zinc and remarked that "the occurrence of the zinc was somewhat unexpected." In the extensive mining of oxidized zinc ores during the last few years, ore of this type has been found only in small quantities and of a grade too low for shipment except during a short time when the price of zinc was abnormally high. It is indeed striking that none of the many specimens of ores and vein matter taken during the extensive study of the ores in the earlier days proved to contain any considerable quantity of zinc carbonate.

In 1889, after a period of extensive development, during which many of the oxidized lead bodies had been followed down to the

sulphide zone. Blow¹ called attention to the abundance of zinc blende just below the zone of oxidation and offered the conclusion that it was the result of downward sulphide enrichment. In his own words,

The zinc sulphides are the most widely disseminated and show plainly the result of their more ready solubility than the other sulphides and the redeposition of a large portion of the zinc which has thus been removed from the carbonate ores. This fact is clearly shown in many ways, but most satisfactorily just at the line of transition. The sulphides first encountered are invariably heavy sulphides of zinc, carrying a little iron and very little lead. They have a close crystalline structure and lie in a laminated form, the lines of fracture being nearly vertical. Upon these cleavage planes crystals of cerussite are found, and often a small incrustation of native silver. Such deposits, where first encountered in passing from oxidized to unoxidized ores, are always lowest in silver. In their further extension the zinc gradually grows less and the laminated structure disappears. Beyond this, again, the zinc sulphides appear to predominate along cleavage and contact planes with the gray porphyry, or along the lines of minor faults and cracks in the limestone. Such characteristics are also universally observed in other instances besides those of Iron Hill. * * *

In advancing further within the ore shoots the zinc appears to lose its preponderance over the other sulphides. * * * It seems probable that a large proportion of the zinc, which was totally removed from the carbonate ores, has been redeposited as a sulphide; and principally just below the line of complete oxidation, by surface waters, and such redeposition has advanced and increased *pari passu* with the limit and extent of such oxidizing action.

As a corollary of the above, it is believed that at the present stage of development in Leadville, the sulphide of zinc forms a larger part of the unoxidized ores than will be found in future and deeper exploration.

This conclusion, in view of the fact that no zinc carbonate ore bodies had then been discovered or recognized, seemed very plausible from the evidence in hand. It was evidently adopted by Emmons and Irving,² who wrote in 1907:

The hydrous zinc sulphate is presumably more soluble and less stable than the corresponding iron sulphate. In Leadville, like gypsum, which should have been formed by the reaction between iron sulphate and limestone, it is practically absent from the oxidized zone and must have been carried away in solution or redeposited as a sulphide below the zone of oxidation. It has, in fact, been observed that the sulphide ores are much richer in zinc blende immediately below the limit of oxidation than elsewhere.

This hypothesis of downward enrichment of zinc blende tended to delay the search and discovery of the zinc carbonate ores, as the possible existence of such ores must have been dismissed from the minds of the geologists and consequently from the minds of the operators.

The field evidence, however, on which this hypothesis was based may be interpreted in another way, as will be shown later; further-

¹ Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, pp. 168-172, 1890.

² Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo.: U. S. Geol. Survey Bull. 320, pp. 32-33, 1907.

more, later developments have shown that rich bodies of zinc blende are not limited to the top of the sulphide zone; and finally, recent experimental evidence and field observations in other parts of the world have shown that such deposition of secondary zinc blende is very unlikely.

After the large shipments of ore in 1910 had attracted wide attention Emmons addressed a letter from Dinard, France, to the Leadville Herald-Democrat,¹ in which he said:

At the time of my first study of the Leadville district, in 1880, I was much puzzled to know what had become of the zinc. * * * I assumed then that owing to the superior solubility of the zinc sulphate, the oxidation products of that metal had been carried much further than those of lead before being transformed into the now stable carbonate, and had possibly been entirely removed in the run-off.

Blow's observation that on Iron Hill secondary zinc blende had accumulated in the upper part of the sulphide zone seemed to account for some of the missing zinc, and from accounts published by you, it is evident that much of it has accumulated as calamine in the zone of change from sulphide to oxide.

Though I have particularly desired to study the zinc of Leadville, I have never been able to, because in 1880 mine workings had not yet reached it, and when I next visited the district (1890) they had gone beyond it, and owing to the soft nature of the ground in that zone the drifts leading to it were for the most part caved and inaccessible.

It certainly seems rather strange that those in charge of mines, when this zone was exploited, did not notice such bodies of calamine as you describe, but it must be borne in mind that calamine is generally a white-brown earthy-looking material, which would not attract attention unless especially sought for, and that it was pay ore rather than material of only mineralogical interest that they were seeking, and at that time zinciferous ores were a particularly undesirable product.

Another reason, mentioned by several writers,² for the failure to recognize oxidized zinc ores is the fact that in the earlier days the presence of zinc in the lead-silver ores and also in the iron ores was a decided detriment, and miners in consequence avoided points where assays showed a considerable percentage of zinc. According to G. O. Argall and E. W. Keith, the presence of zinc was especially noticeable in shipments from the Carbonate Hill and Fryer Hill mines. The object of search in those days was lead-silver ore, and as there was then no market for zinc there was no incentive to look for it, even though some of the early operators may have recognized its character. Argall further states that it was after the gradual depletion of the sulphide ores and in consequence of the increasing expense of deep operations that exploitation turned again to the

¹ This letter, dated Oct. 11, 1910, has been quoted by the Engineering and Mining Journal (Nov. 12, 1910, p. 954) and by H. E. Burton in Mines and Minerals (February, 1911, p. 436).

² Mining World, Dec. 17, 1910, p. 1147. Keith, E. W., Leadville Herald-Democrat, Sept. 20, 1910, p. 1. Argall, G. O., Oxidized zinc ores at Leadville: Eng. and Min. Jour., Aug. 26, 1911, p. 399.

upper levels in search of ore that might not have been profitably mined when first opened and thus led to the discovery of the character and value of the oxidized zinc deposits.

RECENT DISCOVERY OF OXIDIZED ZINC ORE BODIES.

Accounts of the recent discovery of oxidized zinc ores in extensive bodies at Leadville are not in accord.¹ Some state that the discovery was made through the curiosity of a Leadville assayer, who took the time and trouble to determine the contents of a sample of high specific gravity, which had been shown by assays to contain little or no lead, silver, or gold; others state that the character of the material was recognized by those who had discovered and worked oxidized zinc ores elsewhere in the State. According to J. B. McDonald,²

the first silicate of zinc shipped from the State was from the old Madonna mine, at Monarch, Chaffee County, in 1902. * * * Several hundred tons of the ore were shipped. * * * The first carbonate of zinc ever shipped from the State came from the Monarch Pool mine, at Monarch, and the two highest-grade cars of carbonate of zinc ever shipped out of the State to this day came from this mine. One car ran 46.7 per cent and the other 47 per cent zinc.

The following year (1903) Mr. McDonald and Mr. Harry Paul procured a lease on the Eclipse mine at Monarch and shipped a mixed carbonate and silicate ore almost identical in character with that discovered in Leadville seven years later. Mr. McDonald states that in the spring of 1906 he found the first carbonate and silicate of zinc ever found in commercial quantities in the Leadville region. This was at the Hilltop mine, in the Horseshoe district, which adjoins the Leadville district on the divide between Lake and Park counties.

The first discovery of ore of this kind within the Leadville district in recent years was made in 1909 by W. E. Jones, a lessee in the Robert E. Lee mine, who found a large body of zinc carbonate. Shipments were made from this body and also from the Penrose dump but were of too low grade for treatment and failed to arouse much interest in oxidized zinc ores. In the following year (1910) the first high-grade zinc ore, reported as calamine, was discovered by H. E. Burton, H. K. White, and Alfred Thielen in a lease at the Hayden shaft of the May Queen mine. This property was the first to ship high-grade calamine ore. After this discovery S. D. Nicholson, manager of the Western Mining Co.'s properties, began a search for oxidized zinc ores in the old workings of the Wolftone and adjoining claims and discovered in them the largest bodies yet found

¹ Leadville Herald-Democrat, Sept. 11, 1910, and Jan. 1, 1911; Eng. and Min. Jour., Nov. 12, 1910, p. 954, and Aug. 26, 1911, p. 399; Min. World, Dec. 17, 1910, p. 1147; Mines and Minerals, Feb. 11, 1911, p. 436; Min. Sci., July 27, 1911, p. 85.

² Personal interview with the writer. A similar account is given in Min. Sci., July 27, 1911, p. 85.

in the district. This discovery resulted in a general search for the ore throughout the district, with the result that smithsonite and calamine in varying amounts were found in a number of properties from Fryer Hill on the north to Weston Pass on the south.

PRODUCTION.

These discoveries were made at a time when there was an increasing demand for zinc, and although shipments of oxidized zinc ores began only at the end of 1910, they became very large in 1911, as shown in the table on page 14, offsetting a marked decline in the production of zinc sulphide ore and increasing the output of metallic zinc in Lake County by 15,243,011 pounds. This increase, in spite of a decrease of 7,996 tons in total shipments of zinc ores from the Leadville district, was due to the higher grade of the oxidized ores. At first only oxidized ores that averaged 30 per cent or more in zinc were shipped, but the increasing price, which culminated at 7 cents a pound late in 1912 and early in 1913, allowed profitable mining of ore containing as low as 17 per cent, and the production of oxidized zinc ores in 1912 greatly increased. Some ore containing as low as 15 per cent was shipped but at a loss. Most of the ore shipped, however, averaged about 30 per cent, and some contained as high as 40 per cent. The average for all shipments was 29.2 per cent.

Owing largely to this increase in price, which allowed several small producers of low-grade ore to ship at a profit, many enthusiastic estimates were made of the vast quantity of ore in reserve; but the rapid decline in price to about 5 cents a pound in the spring of 1913 forced most of the small producers to stop work, and the production for 1913 was less than that for 1912. During the writer's visit to the district in July and August, 1913, only a few properties besides those of the Western Mining Co. at Carbonate Hill were being worked. Ore containing as little as 24 per cent of zinc, however, could be shipped at a profit during the summer, and in October of that year it was stated that 22 per cent ore could be marketed.¹

In January, 1914, new smelting rates made it possible to ship carbonate ore containing only 18 per cent of zinc. The average content of ore shipped during that year was 24.3 per cent, and in 1915 the average was 22.48 per cent. In spite of this opportunity to ship lower-grade ores, and in spite of the reported opening of a large body of zinc carbonate ore averaging 25 per cent zinc in the upper levels of the Woflstone mine in 1915,² the production of oxidized zinc ores, as shown in the accompanying table, continued to decrease during 1914 and 1915, the decline more than offsetting substantial

¹ Eng. and Min. Jour., Oct. 18, 1913, p. 761.

² Mining Press, Mar. 20, 1915, p. 455.

increases in output of zinc sulphide ore. Owing to the extraordinarily high price of zinc in 1915, however, the total value of zinc from Lake County was more than 100 per cent greater than in 1914.

Depletion of the immense deposits in Carbonate Hill was evidently far from compensated during these years by discovery and development of oxidized zinc ore bodies elsewhere in the district. The production of both zinc carbonate and zinc sulphide ore in 1916, however, showed an encouraging increase, though the zinc content of the carbonate ore continued to decrease slightly.

The following figures¹ show the quantities of oxidized zinc ore produced in the Leadville district from the time of the first shipments in 1910 to the end of 1916 and the corresponding quantities of zinc sulphide shipments in the district, the total zinc for Lake County (most of which is from Leadville), and the total zinc for the whole State.

Zinc produced in the Leadville district, in Lake County, and in Colorado, 1909-1916.

Year.	Leadville.				Lake County.		Colorado.	
	Oxidized ores.		Sulphide ores.		Total zinc (pounds, in spelter and oxide).	Value.	Total zinc (pounds, in spelter and oxide).	Value.
	Quantity (short tons).	Per cent of zinc.	Quantity (short tons).	Per cent of zinc.				
1909.....							51,210,200	\$2,765,354
1910.....	8,059	30.4	163,218		56,367,445	\$3,043,842	77,089,648	4,162,841
1911.....	88,905	31.1	79,376	23.3	71,610,456	4,081,796	94,607,456	5,392,625
1912.....	142,782	29.2	104,148	24	105,945,782	7,210,269	132,222,512	9,123,374
1913.....	125,790	27.45	97,704	23	93,842,657	6,255,200	119,346,429	6,683,400
1914.....	113,881	24.3	111,947	21.2	78,763,334	4,016,930	96,774,980	4,935,523
1915.....	82,592	22.48	136,556	22.09	72,498,170	8,989,154	104,694,694	12,989,779
1916.....	85,513	21.52	147,295	21.09	76,785,567	10,289,266	134,285,468	17,994,252

Most of the ore thus far mined has come from the immense body in Carbonate Hill, which extends through the claims controlled by the Western Mining Co. and a few adjoining claims. Smaller amounts have come from Fryer, Breece, Iron, Printer Boy, and Rock hills, showing that the oxidized zinc ores, like the oxidized lead ores, are distributed throughout the district. There is, however, a striking contrast between these two classes of ore, for although large bodies of oxidized lead ore have been mined in all of these hills, the correspondingly extensive bodies of high-grade oxidized zinc ore thus far discovered are limited to the northern part of Carbonate Hill.

¹ Henderson, C. W., Gold, silver, copper, lead, and zinc in Colorado: U. S. Geol. Survey Mineral Resources, 1909 to 1916.

Mines producing oxidized zinc ores, 1910 to 1916.

	1910	1911	1912	1913	1914	1915	1916
Blind Tom					x	x	-----
Bullock			x				-----
Blonger			x				-----
Chrysolite		x	x				x
Dolly B				x	x	x	x
Ellen					x	x	x
Elk					x	x	x
Fannie Rawlings			x				-----
Gambetta			x	x			-----
Highland Chief			x	x	x	x	-----
Iber (Little Johnnie)		x	x	x	x	x	-----
La Plata (Richard)			x	x	x	x	-----
Lillian		x	x	x	x	x	x
Little Chief		x	x	x	x	x	x
Little Ellen					x	x	x
May Queen	x	x	x		x	x	-----
Mikado			x	x			-----
Minnie Lee						x	-----
New Dome (Nisi Prius)		x	x	x			-----
Penrose							x
Polaris						x	-----
Pons			x				-----
Rattling Jack		x	x			x	x
Robert E. Lee				x	x	x	x
St. Louis tunnel				x	x	x	-----
Sardine and Seneca			x	x			-----
Sierra Nevada					x		-----
Smuggler			x	x	x	x	-----
Star Consolidated		x	?	x	x	x	x
Tucson		x					-----
U. S. Smelting, Refining & Mining Co.							x
Western Mining Co.:							-----
Adams		?	x	x			-----
Big Chief		x	x	x	x	x	x
Brookland		?	x				-----
Castleview		x	x	x	x	x	x
Evalyn					x	x	-----
Henrietta		x	x	x			-----
Maid of Erin		x	x	x	x	x	x
Waterloo		?	x	x			-----
Wolfstone		x	x	x	x	x	x
Yak tunnel:							-----
White Cap			x	x	x	x	-----

Among recent developments in the district wholly or partly induced by the mining of oxidized zinc ores are the establishment of a plant at Leadville for the treatment of low-grade oxidized zinc ores and the unwatering of the Downtown, Fryer Hill, and Carbonate Hill sections of the district. In the spring of 1914 the Western Zinc Mining & Reducing Co. began the erection of a zinc oxide plant to treat the oxidized ores.¹ This plant, which had a capacity of 50 tons a day and was designed to treat zinc carbonate ore containing 16 per cent or less of zinc, was put into operation in the fall of 1914² but was operated for only a short time. In 1915, however, it was successfully operated by the Western Zinc Oxide Co. on low-grade zinc carbonate ores, mainly from the Robert E. Lee mine, and was reported in July of that year to be yielding 150 tons a month of a product containing 70 to 80 per cent zinc and realizing \$100 a ton.³ The plant was operated steadily during 1916. In April, 1917, it was reported to be capable

¹ Eng. and Min. Jour., Mar. 28, 1914, p. 676.

² Min. and Eng. World, Nov. 14, 1914, p. 92.

³ Min. Press, July 24, 1915, p. 144.



of treating 60 tons of zinc carbonate a day, and the company was said to be considering an enlargement of the plant to include equipment for roasting sulphide ores.¹

The unwatering of the Downtown section of the district was begun in 1914 with the installation of pumps at the Penrose shaft. It proved an immense undertaking and was not completed until 1916. During that year the projects to unwater the Fryer and Carbonate hills sections were begun. In 1917 they were completed, and shipments of ore, including zinc carbonate, were made from the newly unwatered ground in all the three sections.² Trial shipments of zinc carbonate ore from the Penrose mine yielded 25 per cent of zinc.³

LITERATURE.

Although several short articles, already referred to, have been written on the oxidized zinc ores of Leadville, they deal mostly with history. Only three papers have discussed the occurrence and genesis of these ores at any length. G. O. Argall⁴ in 1911 gave brief descriptions of the mineralogy and occurrence of the ore and discussed the process of oxidation by which the zinc ore was concentrated. Butler⁵ in 1913 described the occurrence and nature of the ore in somewhat more detail and announced the occurrence of two mineral varieties not previously recognized in the district. One of these was an aragonite containing variable proportions of zinc and named by Butler nicholsonite, after S. D. Nicholson, manager of the Western Mining Co., in whose mine the mineral was found. The other mineral was at first thought to be a new species and was named wolftonite, from its discovery in the Wolftone mine. Further study, however, proved this mineral to be hetaerolite, although the Leadville specimens are different in appearance from the type material.⁶ Butler also discussed the origin of the ore and the results of experiments on the determination of the grade of ore and on its concentration.

Philip Argall visited the deposits on Carbonate Hill a few months after the writer's visit and in 1914 published a very interesting paper,⁷ laying special emphasis on the occurrence of gray zinc carbonate ore along fissures in the lower part of the White limestone of

¹ Min. Press, Apr. 14, 1917, p. 519.

² Hoskins, A. J., Unwatering projects at Leadville: Eng. and Min. Jour., Mar. 24, 1917, pp. 483-487. Henderson, C. W., U. S. Geol. Survey Press Bull. 825, p. 3, July, 1917.

³ Min. Press, Mar. 24, 1917, p. 424.

⁴ Argall, G. O., Oxidized zinc ores at Leadville: Leadville Herald-Democrat, Jan. 1, 1911, p. 6. The same article in condensed form appeared in Eng. and Min. Jour. Aug. 26, 1911, p. 399.

⁵ Butler, G. M., Some recent developments at Leadville, second paper, The oxidized zinc ores; Econ. Geology, vol. 8, pp. 1-18, 1913; reprinted with addendum in Colorado School of Mines Quart., vol. 8, pp. 9-21, 1913.

⁶ Written communication by G. M. Butler to the writer.

⁷ Argall, Philip, The zinc carbonate ores of Leadville: Min. Mag. (London), vol. 10, pp. 282-288, 1914.

the Maid of Erin mine—places not exposed at the time of the writer's visit. The zinc carbonate ore there grades into manganiferous siderite a short distance from the fissures. Argall's descriptions supplement and his conclusions are in accord with those of the writer.

A paper of general interest on the formation of oxidized zinc ores by Wang¹ was published in 1915, over a year after the present report was completed. In this paper several experiments were described, some of which confirmed conclusions stated by the present writer regarding the genesis of the Leadville ores and none of which offered conflicting evidence. Wang's conclusion, however, that there is no definite order in the formation of smithsonite and calamine is not confirmed by study of the Leadville ores, in which smithsonite everywhere precedes calamine. The only specimen from Leadville described by Wang is one composed mostly of calamine with some smithsonite, in which hematite and limonite are concentrated along the partings and cleavage cracks of calamine.

MINERALOGY.

The zinc-ore and associated minerals noted in the oxidized zinc deposits of the Leadville district are given in the following lists:

Zinc-ore minerals.

Smithsonite.
Hydrozincite.
Aurichalcite.
Nicholsonite (zinciferous aragonite).
Calamine.
Hetaerolite ("wolf-tonite").
Chalcophanite.
Zinciferous clay.
Deschenite.

Associated minerals.

Iron oxides.
Manganese oxides (?).
Dolomite.
Manganosiderite.
Calcite.
Aragonite.
Barite.
Plumbojarosite.
Opal or chalcedony.
Chert.
Quartz.
Sericite.
Kaolin.
Sulphides.
Native silver.

ZINC-ORE MINERALS.

SMITHSONITE.

Smithsonite, the zinc carbonate (ZnCO_3), is by far the most abundant of the oxidized zinc minerals. The pure mineral should contain 52 per cent of metallic zinc, but owing to the presence of impurities, the percentage in shipping carbonate ore of the better

¹ Wang, Y. T., The formation of the oxidized ores of zinc from the sulphide: Am. Inst. Min. Eng. Bull., September, 1915, pp. 1959-2012.

grades is rarely above 40 and commonly not much above 30. Smithsonite occurs in two varieties, deposited in different stages. Both may commonly be noted in a single specimen. The older variety (Pls. I, A; II, A) contains isomorphous mixtures of iron, magnesia, and manganese carbonates. It forms a dense gray to pale-brown mass of microscopic grains, in part relatively massive and in part containing numerous small cavities or pockets. The younger varieties (Pls. III, A; IV, A) is a fine drusy growth, colorless to white or locally pale greenish where free from foreign matter but usually of brown appearance, owing to the brown iron oxide to which it is attached. The dusty smithsonite has a weaker absorption and a lower index of refraction than the dense variety, properties which indicate a higher percentage of zinc, whereas the dense variety is correspondingly high in iron. Individual grains of the dense material, however, are so extremely fine and so complex in composition that measurements of their indices can not be made with sufficient accuracy to give more than a rough approximation to the percentage of zinc. The drusy variety lines small pockets and minute fractures in the dense variety, and close inspection shows that in several places it forms minute layers alternating with layers of a black manganese mineral (hetaerolite?) and locally with ferric oxide. (See Pl. IV, A.) Many if not most of the cavities containing calamine have a narrow rim of drusy smithsonite. The crystals of the drusy variety have for the most part curved or corroded faces, but here and there minute though nearly perfect unit rhombohedrons may be found. Occasionally pockets are found containing minute isolated rhombs, more or less corroded, scattered over a surface of brown iron oxide.

No coarsely fibrous or botryoidal smithsonite was seen by the writer, and only one occurrence—in the lower beds of the White limestone in the Maid of Erin mine—has been reported, to his knowledge.¹ In this respect the Leadville smithsonite is sharply contrasted with that in many well-known deposits of oxidized zinc ores, and the absence of these more familiar forms of the mineral may go far toward explaining the failure to realize earlier the position and extent of the oxidized zinc ores in the Leadville district.

HYDROZINCITE.

Hydrozincite, a basic zinc carbonate ($\text{ZnCO}_3 \cdot \text{ZnO} \cdot \text{H}_2\text{O}$), has been reported to occur here and there as a dull-lustered white, soft, earthy alteration product of smithsonite.¹ In the workings accessible to the

¹ Argall, Phillip. The zinc carbonate ores of Leadville: *Min. Mag.* (London), vol. 10, p. 284, 1914.

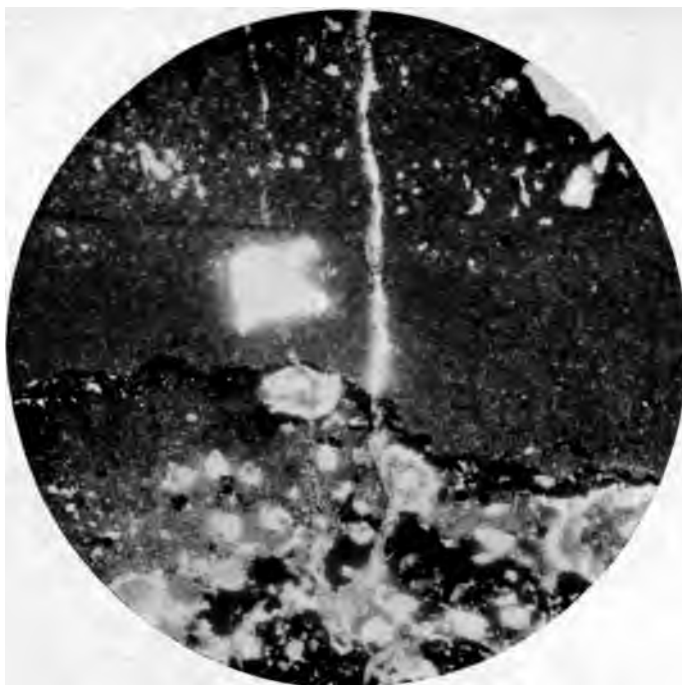
² Butler, G. M., Some recent developments at Leadville, second paper, The oxidized zinc ores: *Econ. Geology*, vol. 8, p. 8, 1913; reprinted in *Colorado School of Mines Quart.*, vol. 8, April, 1913.



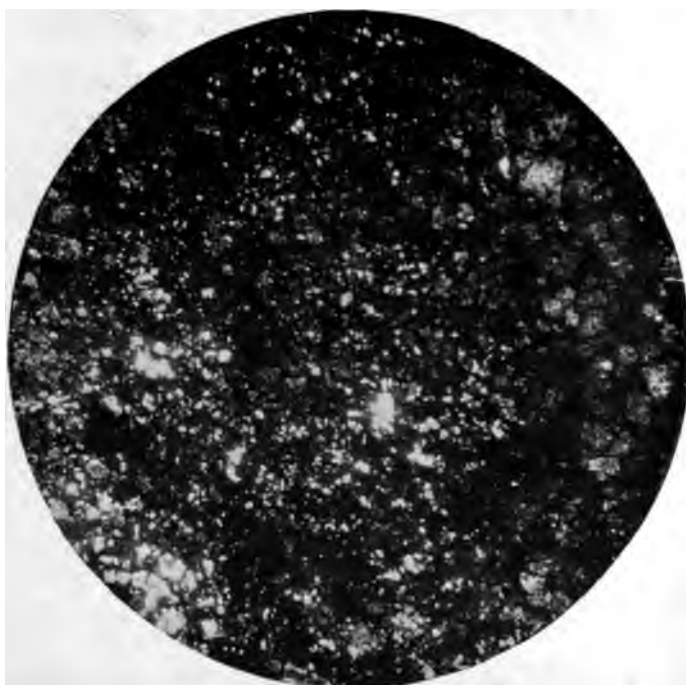
A. GRAY ZINC CARBONATE ORE.



B. CHALCOPHANITE AND CALAMINE COATING BROWN ZINC CARBONATE ORE.



A. PHOTOMICROGRAPH OF GRAY ZINC CARBONATE ORE INCLOSING REMNANTS OF SULPHIDE ORE.



B. PHOTOMICROGRAPH OF ZINC CARBONATE REPLACING MANGANOSIDERITE.

writer, however, the only earthy white material found in the oxidized zinc ores proved, on testing, to be the zinciferous clay, described on pages 24-28.

AURICHALCITE.

Aurichalcite is a basic carbonate of zinc and copper, $2(\text{Zn,Cu})\text{CO}_3 \cdot 3(\text{Zn,Cu})(\text{OH})_2$, whose zinc content ranges, according to different analyses, from 50 to 59 per cent, and whose copper content ranges from 15 to 22 per cent. The pure mineral, according to Penfield,¹ contains 53 to 54.4 per cent of zinc and 20 to 21.2 per cent of copper. The pure mineral is of pale-green to sky-blue color, of pearly luster, and very soft and occurs in drusy coatings or divergent tufts of columnar or needle-like crystals.

The only deposits of aurichalcite noted by the writer in Leadville were in two small stopes above the first level of the Ibex No. 1 (Little Johnny claim). Here the aurichalcite occurs as pale bluish-green crystals forming druses or cavity fillings in light-brown zinc carbonate ore. (See Pl. V, *A*.) In thin section (Pl. V, *B*) the pocket fillings were found to consist of a mixture of aurichalcite and calamine. The calamine predominated, forming diverging groups of bladelike crystals, in and through which were scattered tufts of fine needle-like to fibrous crystals of aurichalcite. A thin rim of drusy smithsonite separated the calamine and aurichalcite in places from the massive brown ore. One of the pockets was found to have a matrix of nearly or quite isotropic silica, in which the crystals of aurichalcite and calamine were embedded. The silica preserved to some extent the granular texture of the massive carbonate ore, proving that the "pocket" had grown in part, or been enlarged, by replacement of the massive ore, and indicating that the zinc in the calamine and aurichalcite had been, at least in part, derived from the zinc in the massive ore. The source of the copper is not apparent. It is said that ore of this type from the Ibex No. 1 has run as high as 4 per cent copper, but that no allowance for the copper is made by the ore buyers. Ore of a similar kind is said to have been mined in the Rattling Jack claim, whose shaft is a short distance southeast of the Ibex No. 1 shaft.

A few microscopic needles of aurichalcite were found in a thin section (Pl. V, *C*) of a calamine-quartz vein cutting low-grade reddish-brown zinc ore in the Belgian mine (Fenton's lease in 1913). Here also the aurichalcite grew simultaneously with the calamine; the two zinc minerals grew inward from the sides of the vein, and their terminations are embedded in a central filling of chalcedonic quartz. Some of the aurichalcite needles are bent, and fragments

¹ Penfield, S. L., One the chemical composition of aurichalcite: *Am. Jour. Sci.*, 3d ser., vol. 41, pp. 106-108, 1891.

of calamine blades, which may have been broken from the margins, are inclosed in the central portion of the vein, suggesting that there was a sluggish flowing of fluid (or gelatinous) silica during or just after the growth of the aurichalcite and calamine crystals.

The fact that these were the only occurrences of aurichalcite noted in the district indicates that the mineral is a very minor constituent of the general run of the oxidized zinc ores. Its relative abundance in the Ibex, which lies in the copper-gold belt, is significant, and its occurrence in considerable quantities is doubtless limited to this belt.

CALAMINE.

Calamine is a hydrous silicate of zinc, whose formula may be written $H_2Zn_2SiO_5$, $(ZnOH)_2SiO_3$, or $H_2O.2ZnO.SiO_2$. The pure mineral contains 54.2 per cent of metallic zinc. It occurs typically in fine to coarse druses of white to colorless bladed crystals (Pl. IV), or in aggregates of diverging crystal groups, which may partly or completely fill cavities (fig. 2, p. 42). Sheaf-like aggregates, composed of crystals welded along their brachypinacoids, are occasionally found. The crystals in these cavities are tabular parallel to the brachypinacoid, which is vertically striated. Many of the crystals are terminated by a blunt point formed by two macrodomes; others by a sharper point where the blunt macrodomes are subordinate to steep macrodomes. Less commonly the nearly flat brachydomes predominate, producing a blunt chisel-like termination, and in a few specimens the "chisel edge" was seen to be truncated by the basal pinacoid. One small pyramid face was noted by Butler.¹ Prism faces are present but not conspicuous. The calamine also fills small fractures, in a few of which it is accompanied by amorphous or microcrystalline silica. In one exceptional specimen, found by R. S. Fitch on the dump at the Adams shaft, August, 1913, calamine crystals are coated with minute quartz crystals. The calamine crystals have grown upon both massive and drusy smithsonite, and on red and brown iron oxides and black manganese oxides. (See Hetaerolite.) They may inclose small particles of the iron and manganese minerals and be correspondingly darkened in color. They are also found in pockets or fractures in limestone near zinc carbonate ore bodies, and some veinlets cut hetaerolite and zinciferous clay ore, both of which are described below. One specimen, found on the May Queen dump, was so filled with brown oxide of iron as to have a brown opaque appearance, and only its crystal habit gave a clue to its identity. In this and certain other specimens the calamine appears to have grown, at least in part, by the replacement of brown massive smithsonite ore

¹ Butler, G. M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, p. 7, 1913.



A. BROWN ZINC CARBONATE ORE WITH FINE DRUSES OF SMITHSONITE



B. PHOTOMICROGRAPH OF SPECIMEN SHOWN IN A.



A. BROWN ZINC CARBONATE ORE WITH DRUSES OF CALAMINE.



B. CALAMINE DRUSE COATING BROWN ZINC CARBONATE ORE,

along cavities or fractures. In still other specimens, where the calamine rests upon other drusy minerals or fills a network of fractures inclosing sharply angular fragments of brown carbonate ore, the calamine was unquestionably deposited by infiltrating waters without detectable replacement.

HETAEROLITE ("WOLFTONITE").

The mineral hetaerolite was not recognized at Leadville until the development of the oxidized zinc ores was begun. It was at first believed to be a new species and was therefore named wolftonite,¹ after the mine in which it was found, but further study proved it to be hetaerolite. It is composed principally of oxides of zinc and manganese, with smaller amounts of silica and water. Opinions differ as to its chemical formula. The mineral was first described by Moore² in 1877 from a specimen found at the Passaic zinc mine, Sterling Hill, near Ogdensburg, Sussex County, N. J. Moore described the physical properties and occurrence of the mineral and stated it to be a zinc hausmanite ($\text{ZnO.Mn}_2\text{O}_3$)³ but published no analyses. It occurred in association with chalcophanite in ocherous limonite, the chalcophanite usually forming a thin coating over it.

In 1910 Palache⁴ studied a new lot of material from Franklin Furnace, N. J., and agreed with Moore that the hetaerolite was a zinc hausmanite. He assigned it to the tetragonal system of crystallization and stated that it had an indistinct cleavage. The material was analyzed by W. T. Schaller, of the United States Geological Survey (see column 1 on p. 23), and shown to contain small amounts of silica and water, the latter being attributed to a slight admixture of chalcophanite.

In 1913 Ford and Bradley⁵ published a description and analysis of a specimen of the Leadville hetaerolite, taken from the Wolftone mine. They described it as a rare vug-filling mineral, found with a radiating mammillary structure, whose outer surfaces are generally smooth and rounded. The mineral showed a splintery fracture, and individual splinters showed a prismatic structure. Under the microscope the finest fragments were birefringent and had an extinction parallel to the prism edges, but no further indication of its crystal form could be discovered. Its hardness was found to be between 5.5 and 6, and its specific gravity was determined as 4.6. Its luster was

¹ Butler, G. M., op. cit., p. 8.

² Moore, G. E., Preliminary notice of the discovery of a new mineral species: *Am. Jour. Sci.*, 3d ser., vol. 14, p. 423, 1877.

³ The formula for hausmanite is Mn_2O_3 or $\text{MnO.Mn}_2\text{O}_3$.

⁴ Palache, Charles, Contributions to the mineralogy of Franklin Furnace, N. J.: *Am. Jour. Sci.*, 4th ser., vol. 29, pp. 177-187, 1910.

⁵ Ford, W. E., and Bradley, W. H., On hetaerolite from Leadville, Colo.: *Am. Jour. Sci.*, 4th ser., vol. 35, pp. 600-604, 1913.

submetallic, its color dark brownish to black locally, with a bright varnish-like exterior, and its streak dark chocolate-like brown. It was infusible, but on charcoal with sodium carbonate gave the characteristic zinc oxide coating and with fluxes gave the color reactions indicative of manganese. It was easily dissolved in hydrochloric acid, giving off chlorine gas. In the closed tube it yielded water but did not give off oxygen gas. The index of refraction of hetaerolite was determined by Ford and Bradley to be above 1.78. It was determined by E. S. Larsen, of the United States Geological Survey, from material collected by the writer to be 2.19 and 2.22.

The writer can add to the above description that the mineral is of widespread occurrence in the oxidized zinc deposits of Leadville, though he found no specimens equal in size to those found in one part of the Wolftone mine. It has also been recently found by Philip Argall on the fourth level of the Tucson mine, filling small fractures in manganosiderite, well below the levels where oxidized zinc ores have been mined.¹ The mineral occurs mostly as thin drusy bands, alone or alternating with smithsonite, around cavities; also as fillings of small fractures, or as linings of fractures that are centrally filled with calamine or zinciferous clay. Its surface may be exposed, or it may be covered by calamine druses, the crystals of hetaerolite appearing to end abruptly where those of calamine begin. In some specimens small central clusters of distinct hetaerolite crystals grade outward into black stains that spot or mottle a considerable part of the brown carbonate ore. This relation leads to the suggestion that all the black manganese oxide stains and spots in the zinc carbonate ores may be incipient segregations of hetaerolite and not of psilomelane, as would at first be supposed. Wherever seen these black stains bear the same paragenetic relations to the later smithsonite and to calamine as the undoubted occurrences of hetaerolite. Locally hetaerolite may be the most conspicuous mineral in the ore, giving it a black or brownish-black color. In one specimen of this character, from the Tucson mine, the hetaerolite crystals are very distinct, having grown along intersecting fractures and inclosing dark-brown soft, earthy material of low grade. In other specimens of similar color the mineral is not visibly crystallized. The Tucson specimen strongly indicates that the hetaerolite was formed by the segregation of zinc and manganese from the massive carbonate ore, which left a residue composed largely of iron oxides. This origin is also suggested by several other specimens, some of which contain undoubted hetaerolite and others only the black stains.

¹ Specimen taken in June, 1914, and sent to the writer for identification.

In column 1 below is an analysis made by W. T. Schaller¹ of hetaerolite from Franklin Furnace, N. J.; in columns 2 and 3 are analyses of the Leadville hetaerolite made respectively by Bradley² and by Chase Palmer, of the United States Geological Survey; and in column 4 a partial analysis by Haigh.³

Analyses of hetaerolite.

	1	2	3	4
Mn ₂ O ₃	60.44	MnO 50.34	49.13	45.9
O		5.90	5.50	
Fe ₂ O ₃ .....	.77		.67	5.9
ZnO	33.43	37.56	37.66	37.1
CaO		Trace.	Undet.	
SiO ₂	1.71	2.60	2.91	a 2.0
H ₂ O	2.47			
H ₂ O+	1.42	4.36	3.78	4.7
	100.24	100.94	99.65	95.6

^a Insoluble.

In discussing analysis 2, Ford and Bradley state that the structure of the mineral was such as to suggest that the silica is due to the presence of calamine, and that if so about 10 per cent of calamine is present—a large amount to escape discovery; but they thought that the fibrous structure of the hetaerolite might well conceal this amount. By recalculation, with allowance for the calamine, analysis 2 is found to correspond closely to the formula $2\text{ZnO} \cdot 2\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$. Recalculation of analysis 1, including H₂O but not SiO₂, yielded the same formula, which Ford and Bradley conclude should be the formula for hetaerolite, instead of ZnO.Mn₂O₃, as stated by Moore and later by Palache; but they add that “it may be that the exact composition of hetaerolite can not be settled until purer material can be analyzed.”

The best specimens collected by the writer show the hetaerolite to be a distinctly earlier growth than calamine, and the purest material, when crushed to a fine powder and examined under the microscope, gave no indication of calamine, even fine specks of which should be easily distinguishable from the hetaerolite. Chemical analysis (column 3 in the preceding table) shows it, however, to be practically identical with the material analyzed by Bradley (column 2). G. M. Butler⁴ has expressed the conviction that the silica is an essential constituent of the mineral but has not suggested a corresponding formula. Nevertheless, the fact that silica and the excess of ZnO over that necessary for the ratio $2\text{ZnO} \cdot 2\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$ are in the same ratio as in calamine is certainly significant, although just what the significance is must for the present be left to speculation.

¹ Palache, Charles, op. cit., p. 180.

² Ford, W. E., and Bradley, W. M., op. cit., p. 602.

³ Haigh, G., partial analysis quoted by Ford and Bradley.

⁴ Written communication.

CHALCOPHANITE.

Chalcophanite, like hetaerolite, is a manganese-zinc oxide, with the formula $(\text{Mn}, \text{Zn})\text{O} \cdot 2\text{MnO}_2 \cdot 2\text{H}_2\text{O}$, containing about 21 per cent of zinc oxide.¹ It is closely associated with hetaerolite, both at Franklin Furnace, N. J., and at Leadville, Colo. It differs from hetaerolite in certain physical and chemical properties. In some specimens collected by the writer at Leadville it forms druses of minute tabular crystals of the rhombohedral system, coating botryoidal surfaces and filling occasional cracks in hetaerolite. In others it forms foliated crusts coating brown smithsonite and covered in turn by calamine druses. (See Pl. I, B.) Dana states that it also forms stalactitic and plumose aggregates. Its hardness, as given by Dana, is only 2.5; its specific gravity 3.91. Its luster is metallic and brilliant; its color bluish black to iron-black; and its streak chocolate-brown. In the closed tube it gives off water and oxygen and exfoliates slowly, and its color changes to a golden bronze. Before the blowpipe a similar change of color takes place, accompanied by slight fusion on thin edges, and it is this bronzy appearance that has given rise to the mineral name.

Since the above paragraph was written specimens of Leadville chalcophanite collected by F. B. Laney have been studied by Ford,² whose description verifies the properties above mentioned. He found that very thin plates under the microscope are sufficiently transparent to give a negative uniaxial interference figure.

ZINCIFEROUS CLAY.

Three varieties of zinciferous clay have been recognized in the Leadville mines—white, brown, and black. The white and brown are the most abundant. The white clay (Pl. VI, A) is very similar in appearance to kaolin and is one of the materials included under the local name "Chinese talc." The fresh material, however, is harder (about 3) and of more waxy luster than kaolin and does not slake or become plastic even when immersed in water for several days. Its fracture is conchoidal. Weathered or leached portions of it are of earthy appearance and slake readily in water. It has been found at the base of porphyry sheets in the Waterloo³ and New Dome mines, forming in the latter a layer 1 to 2 feet thick that separates the sill from an underlying body of reddish-brown zinc carbonate ore. It has also been found in the Yankee Doodle mine, where it forms a layer about 2 feet thick immediately beneath a thin bed of silicified

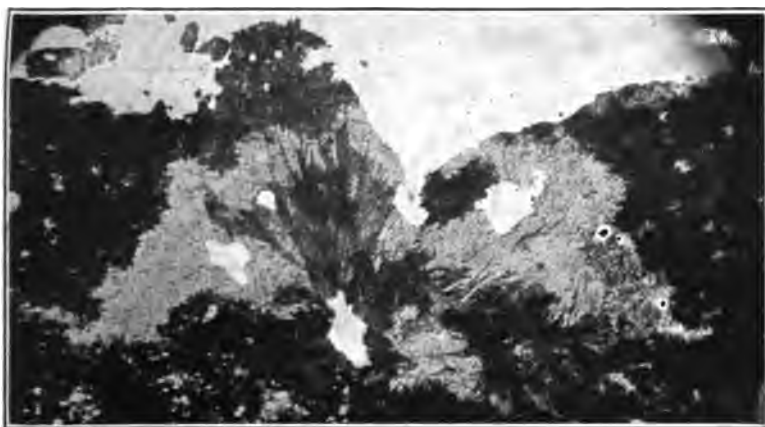
¹ Dana, J. D., *System of mineralogy*, 6th ed., p. 256.

² Ford, W. E., *Mineralogical notes*: *Am. Jour. Sci.*, 4th ser., vol. 38, p. 502, 1914.

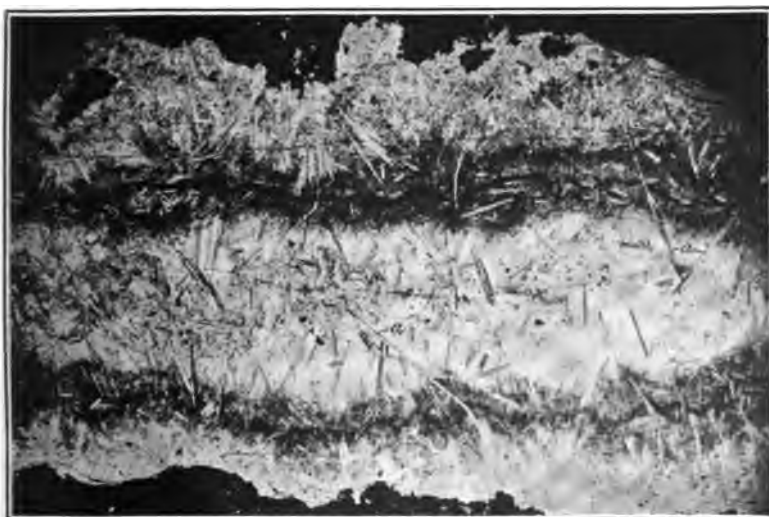
³ Emmons, S. F., *Geology and mining industry of Leadville, Colo.*: U. S. Geol. Survey Mon. 12, p. 560, 1886. Hillebrand, W. F., *idem*, p. 605.



A. BROWN ZINC CARBONATE ORE WITH DRUSES OF AURICHALCITE.



B. PHOTOMICROGRAPH SHOWING AURICHALCITE AND CALAMINE FILLING CAVITY IN BROWN ZINC CARBONATE ORE.



C. PHOTOMICROGRAPH OF VEIN OF CALAMINE, AURICHALCITE, AND OPALINE SILICA IN LOW-GRADE BROWN ZINC ORE.



A



E



B



C



D

- A. WHITE ZINCIFEROUS CLAY.**
B. BROWN DENSE ZINCIFEROUS CLAY.
C. BROWN BANDED ZINCIFEROUS CLAY.
D. E. ARAGONITE FILLING CAVITIES IN BROWN IRON OXIDE.

shale. These occurrences are of sufficient size to be called small ore bodies. Here and there are fissure deposits and small patches and pocket fillings of clay in the zinc carbonate ore bodies.

One specimen found on the New Discovery dump contains calamine veinlets, locally expanded into drusy pockets, so distributed as to suggest that the calamine was formed in shrinkage cracks from material extracted from the clay.

Under the microscope the clay from the Yankee Doodle appears as an interlocking aggregate of minute fibers, of pale-brown color, non-pleochroic, with rather strong birefringence and positive elongation. Its mean index of refraction is a little above 1.58. The general appearance of the fibers is very similar to that of sericite fibers. Clay of similar megascopic appearance, from a pronounced fissure in the Maid of Erin mine, has optical properties more like those of kaolin, being traversed by a network of sericite-like fibers of higher birefringence and containing a few small calamine crystals. These features, together with the relatively low specific gravity of the material, suggest that it is kaolin containing a small percentage of zinc, mostly in the form of the sericite-like mineral.

The brown variety is more widely distributed but is nearly all limited to small deposits, such as the light-brown seams along bedding and joint planes and a few cavity fillings. Those along bedding and joint planes are of bright waxy luster and of uniform dense texture (Pl. VI, *B*), those filling vugs are of more or less waxy luster and may have a pronounced finely banded structure (Pl. VI, *C*), strongly resembling that of a sedimentary clay. Both varieties slake rapidly in water but lack the high degree of plasticity so characteristic of ordinary clays. The bright waxy material slakes into small chips or splinters but does not become plastic; material somewhat softened and dulled by weathering has a tendency to become plastic but lacks the stickiness of ordinary clay, as well as the characteristic odor.

An exceptional occurrence of the brown variety, sufficiently large to be called a small ore body, was seen in the Belgian mine (Fenton's lease in 1913), replacing limestone along fissures just beneath a sheet of Gray porphyry. It was identical in appearance with low-grade zinc carbonate ore but yielded no effervescence when immersed in hydrochloric acid. In this section it was found to consist of aggregates of the minutely fibrous sericite-like mineral, more or less stained and obscured by iron and manganese oxides. Microscopic vugs contained growths of the same mineral with radial arrangement around the borders. The larger of these vugs, or local enlargements of veinlets, contain calamine and the sericite-like mineral so intimately mixed as to indicate that the two must have grown at the same time, though the sericite-like mineral evidently began first, giving rise to the radial borders. It was traversed by many short

veinlets of calamine with black borders of manganese oxide. Other manganese spots and streaks were also present.

A partial analysis by R. C. Wells shows the presence of 17.8 per cent of insoluble matter and 18.7 per cent of zinc oxide (or 15 per cent of zinc). The remainder, as shown by qualitative tests, contained a large amount of iron oxide and small amounts of magnesia and lime. The insoluble matter doubtless indicates the amount of silica in the sericite-like mineral, or zinciferous clay. The zinc oxide represents a little calamine as well as the sericite-like mineral. The material evidently consists essentially of zinciferous clay, a little calamine, iron oxide, and a little manganese oxide.

The black variety was noted in conspicuous amount only at one place, where the white clay in the Yankee Doodle mine was locally stained by manganese oxide.

The chemical composition of the zinciferous clays is shown by the following analyses:

Analyses of zinciferous clays.

	1	2	3	4	5
SiO ₂	37.54	35.97	35.33	35.57	36.49
Al ₂ O ₃	24.76	8.81	10.36	10.80	7.09
Fe ₂ O ₃.....	.64			.40	2.48
FeO.....				Undet.	Undet.
MgO.....	.71	.80	.71	.82	.97
CaO.....	.63	1.67	1.62	.48	1.44
ZnO.....	18.43	35.40	33.05	31.49	33.46
PbO.....				None.	Undet.
Na ₂ O.....	.36			Undet.	Undet.
K ₂ O.....	.66			Undet.	Undet.
H ₂ O+.....	* 11.07	* 7.20	* 7.42	6.32	7.06
H ₂ O-.....	5.03	10.26	11.64	Undet.	Undet.
CO ₂				None.	Undet.
P ₂ O ₅				Undet.	Undet.
Zn.....	100.10	100.31	100.15	† 86.88 25.30	88.99 26.88

* Hillebrand's analysis as tabulated gave only total water, but the amount of hygroscopic water in each analysis is stated in the text (op. cit., p. 605).

† By comparison with analyses 1, 2, and 3, the deficiency appears to be chiefly hygroscopic water.

1, 2, 3. "Alteration product of porphyry," Lower Waterloo mine. W. F. Hillebrand, analyst. U. S. Geol. Survey Mon. 12, p. 603, 1886.

4. White zinciferous clay, Yankee Doodle mine. George Steiger, analyst.

5. Brown zinciferous clay, New Discovery mine. George Steiger, analyst.

The first three analyses represent material obtained directly under porphyry; the fourth represents the Yankee Doodle deposit, beneath a silicified shaly bed; the fifth represents the brown, finely banded type. In spite of variations in the mode of occurrence and appearance, the five analyses are very similar to one another in many respects, but attempts to calculate the mineral composition of the ore yield varying and only inconclusive results. The Yankee Doodle material (No. 4), after kaolin and calamine are calculated, has still an excess of silica and zinc, the molecular proportion of the former being a little more than double that of the latter. In the brown banded

variety (No. 5) the alumina and all the zinc can be assigned to kaolin and calamine, respectively, leaving an excess of silica and combined water in the approximate ratio of 11 to 2. Attempts to find some definite relations between certain constituents by plotting their percentages on a diagram (fig. 1) do not give very definite evidence, except that the percentage of zinc oxide (ZnO) varies inversely as that of alumina (Al_2O_3). The birefringence of the clays shows that crystalline matter is present, and it may be suggested that they contain kaolin or some closely related aluminum silicate, its optical properties changed by dissolved impurities, but if it were suggested that such an aluminum silicate held the other constituents in solid solution, it would be necessary to assume that one molecule of it could hold in solution several molecules of each of the other substances—a questionable property. The low-grade clays, furthermore, show in thin section that the higher birefringent mineral forms a network impregnating a mass with optical properties like those of chalcedonic silica and kaolin. If the highly birefringent portion could be analyzed separately it would probably show as high a ratio of zinc oxide to alumina as the high-grade clays. The fact that the percentage of zinc oxide varies inversely as the percentage of alumina suggests replacement by zinc of aluminum in the kaolin molecule. The low-grade deposits indicate that such replacement has occurred in

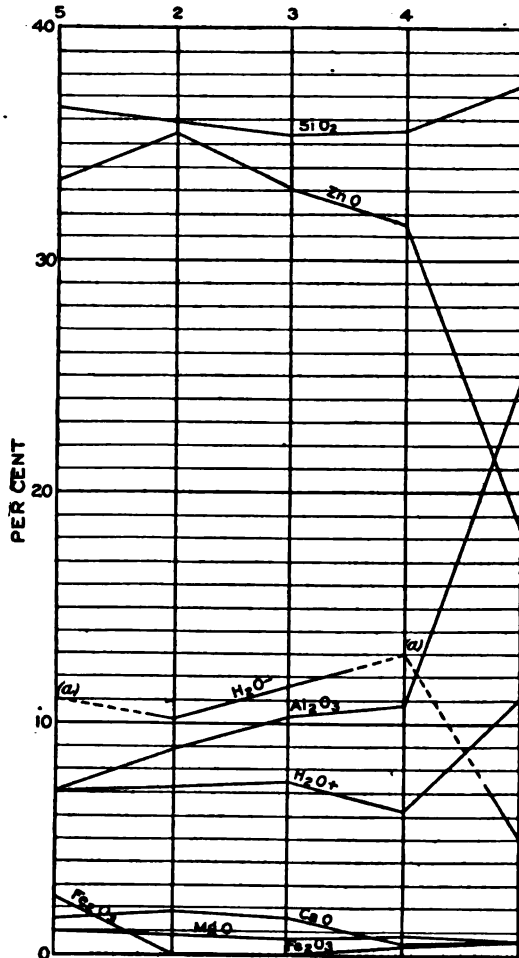


FIGURE 1.—Diagram showing percentages of constituents in zinciferous clays, arranged in order of increasing alumina.

clays previously deposited, but at least some of the high-grade clays indicate that zinc has taken the place of aluminum in solution and that the zinciferous clay has resulted from direct chemical precipitation.

Whatever its true nature, the zinciferous clay has certain relations to definite minerals, as is shown by its contemporaneous deposition with calamine, described on page 20. This relation may suggest that when zinc is above a certain ratio to alumina its excess may crystallize as calamine, but analyses of Missouri "tallow clays"¹ hardly bear out this suggestion. The veinlets and pockets of calamine in the clay, mentioned on page 20, suggest that under favorable conditions the clays that were formed first may later separate into calamine, silica, and kaolin, the silica and kaolin remaining as a microscopic mixture. The fact that zinc and silica, in the absence of alumina, crystallize readily as calamine and opal or chalcedony or quartz is demonstrated by the intimate association of these minerals in several places in the Leadville district. The presence of alumina therefore seems the critical factor in causing the deposition of the clays instead of calamine and other distinct minerals.

DESCHENITE.

According to Emmons and Irving,² deschenite, or the vanadite of lead and zinc, is found as an accessory and rather rare mineral associated with the ore bodies, but no description of its mode of occurrence is given. This mineral was not found by the writer.

ASSOCIATED MINERALS.

IRON OXIDES.

By far the greatest part of the oxidized zinc ores, of both high and low grade, are colored brown or reddish brown by oxides of iron. The ores contain both limonite and turgite, as suggested by their colors and by calculation of the analyses given on page 47, and perhaps also goethite and earthy hematite. Besides coloring the ores, these oxides form large masses of siliceous iron ore of varying grades, some of which have been found above and others beside bodies of oxidized zinc ore. Small masses or segregated deposits of brown iron oxide containing negligible amounts of zinc are also found here and there within the zinc ore bodies and even, rather exceptionally, under them. Iron oxide appears to have been deposited at all stages, from the earliest carbonate ore stage down to

¹ Seamon, W. H., The zinciferous clays of southwest Missouri and a theory as to the growth of calamine of that section: *Am. Jour. Sci.*, 3d ser., vol. 39, pp. 38-42, 1890.

² Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo.: U. S. Geol. Survey Bull. 320, p. 33, 1907.

the present time. In a thin section of a specimen from a zinc stope on the Tucson No. 1 level the iron oxide preserves the texture of the original dolomite (Blue limestone) and was evidently deposited together with silica before or quite as early as any zinc carbonate ore. The bodies of iron oxide accompanied by kaolin and silica, which are commonly found in layers from 6 inches to 5 or 6 feet in thickness between overlying lead carbonate stopes and underlying zinc carbonate stopes, were also probably deposited during or just before the first zinc carbonate stage, but they may be in part residual, having been produced by re-solution and downward migration of the topmost parts of the zinc carbonate ore bodies. The iron oxide ores of shipping grade, so far as they have been seen in contact with or in close proximity to the oxidized zinc ores, appear to have been deposited as early as the first stage of zinc carbonate. The iron oxides in the brown zinc ores have been for the most part derived from the oxidation of ferrous carbonate, which was a constituent of the zinc carbonate of the first stage. There was evidently more or less migration in solution of some of this iron before oxidation, thus accounting for the local segregated deposits within and below the zinc ore bodies. Gray zinc-iron carbonate ore may be seen to-day partly stained by iron oxide that is evidently still in process of formation.

MANGANESE OXIDES.

Black oxide of manganese occurs in much the same variety of ways as the red and brown oxides of iron and needs no detailed description. Although much or all of the black manganese oxide occurring outside of the zinc ore bodies is psilomelane, accompanied by small amounts of pyrolusite, it seems probable that the black stains and coatings in or on the zinc ores is the zinc-manganese mineral hetaerolite, accompanied in places by chalcophanite, both of which have already been described. (See pp. 21-24.)

DOLOMITE.

Dolomite occurs only as unreplaced portions of wall rock (Blue or White limestone), either as inclusions within the zinc ore bodies or as incomplete replaced walls. Analyses of different ore samples show varying but small amounts of magnesia, usually or always in too great a ratio to lime to form dolomite. It appears that during the replacement of dolomite, the lime content was nearly or quite all removed, whereas a small amount of magnesia remained with the ore.

MANGANOSIDERITE.

Manganosiderite, like dolomite, has been found as inclusions or replaced remnants in the oxidized zinc ore bodies of the Maid

Erin mine. These inclusions are of especial interest, as they prove that manganosiderite, as well as dolomite, has been replaced by the zinc carbonate ores. Thin sections of specimens from these manganosiderite inclusions show small amounts of chalcedonic quartz and sericite accompanied by small grains of pyrite, zinc blende, and galena, all of which may be seen preserved in gray zinc-iron carbonate which has replaced the manganosiderite. The manganosiderite can be distinguished from dolomite by its lighter color and higher specific gravity and in thin section by its much stronger absorption. It differs from the gray zinc-iron carbonate ore in its distinctly coarser texture, having a fine to medium grain, whereas the zinc-iron carbonate is microgranular.

CALCITE.

Calcite in the oxidized zinc ores occurs for the most part as colorless to white crystals, here and there lining pockets in ore of all grades and associated iron oxide. Its most common crystal form is the flat rhombohedron of disklike appearance, the sharp edges lying normal to the walls of the cavity. These crystals rest on calamine and in one specimen on hetaerolite and appear to represent the latest mineral growth in the oxidized zinc ore bodies, except, of course, any oxides of iron and manganese that may be forming to-day. Calcite also occurs in small to microscopic veinlets cutting zinc carbonate ore.

ARAGONITE AND NICHOLSONITE.

Aragonite, the orthorhombic form of calcium carbonate (CaCO_3), is occasionally found in close association with the oxidized zinc ores but has not been noted in direct contact with zinc ore minerals. It forms diverging to spherical radiating columnar aggregates, or groups of such aggregates (Pl. VI, *E*), usually if not invariably white. The one occurrence found by the writer formed pockets in brown siliceous iron oxide. So far as its general appearance and mode of occurrence are concerned, aragonite may be mistaken at first glance for calamine; but it lacks the characteristic bladed form of calamine and can further be distinguished by its brisk effervescence in very dilute hydrochloric acid.

The aragonite studied by the writer proved to contain little or no zinc, but a variety containing as much as 10 per cent of zinc was studied by G. M. Butler, who gave it the name nicholsonite. According to Butler,¹

¹ Butler, G. M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, pp. 8 and 9, 1913.

The nicholsonite is identical with aragonite in all but three particulars. Those specimens with high percentages of zinc have a higher specific gravity than aragonite, show a decided adamantine rather than a vitreous luster, and have a better cleavage (good pinacoidal and poor prismatic) than pure aragonite. The variety was found in the oxidized iron-manganese ore in the blue limestone and was named after S. D. Nicholson, of the Western Mining Co., who brought it to the attention of the writer.

BARITE.

Only one occurrence of barite was noted in connection with the oxidized zinc ores. This was in the Little Giant mine, near the boundary between that mine and the Yankee Doodle. The barite formed a rather coarse grained aggregate of crystals, originally white, whose cleavage cracks and boundaries, as well as other fractures, were filled with a yellowish-brown powdery material that effervesced weakly in dilute hydrochloric acid. The material was said to have a low zinc content, but its noticeably high specific gravity was due to the barite rather than to any iron, zinc, or lead.

PLUMBOJAROSITE.

Plumbojarosite, a hydrous sulphate of lead and ferric iron ($\text{PbO} \cdot 3\text{Fe}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 6\text{H}_2\text{O}$), was found in the Yankee Doodle mine in the bottom of an old lead stope, just above a small oxidized zinc stope. It was called "contact matter" but was known to contain considerable lead. The mineral occurs as a yellowish-brown soft, earthy mass, with a rather shiny luster and a smoother feel than is characteristic of iron oxide or iron-stained lead carbonate. Under the microscope the material is essentially homogeneous and consists of minute grains, some of which show a partial to complete six-sided outline under very high magnification. It is much finer grained than the material from Beaver County, Utah, figured by B. S. Butler.¹

Material of the same kind was found by Emmons under Gray porphyry in the Lower Waterloo mine during the first survey of the district and was analyzed by Hillebrand² as follows:

SiO_2	0.36	Bi_2O_3	None.
FeO	44.4	As_2S_3	0.39
Al_2O_3 .....	.23	P_2O_5 .....	.11
CaO	None.	SO_3	25.07
MgO	None.	Cl} .....	.04
K_2O} .....	.15	Ag} .....	.075
Na_2O} .....	.37		
H_2O	8.99		99.685
PbO	19.5		

¹ Butler, B. S., Occurrence of complex and little known sulphates and sulpharsenates as ore minerals in Utah: Econ. Geology, vol. 8, p. 313, 1913.

² U. S. Geol. Survey Mon. 12, p. 606, 1886.

Emmons and Hillebrand, however, did not recognize this material as a distinct mineral species, owing doubtless to its earthy appearance and close resemblance to other materials of varying though similar composition. Plumbojarosite was determined as a distinct species six years later by Hillebrand and Penfield.¹

OPAL, CHALCEDONY, AND QUARTZ.

Silica, usually in a dense form, has been found in small amounts at several different places, usually associated with calamine. The occurrence of amorphous (opal) to chalcedonic silica as the middle of a veinlet with marginal bands of calamine in the Belgian mine and the occurrence of amorphous silica in a vug with calamine and aurichalcite in the Ibex mine have already been described (p. 19; Pl. V, *A* and *B*). On the Mikado dump was found a specimen containing vugs lined with microscopic to visibly crystalline quartz and calamine. A few minute crystals of quartz were seen perched on the sides of calamine crystals. R. S. Fitch, of Leadville, found a similar but much better specimen in which calamine crystals were almost completely coated with fine druses of minute but typical quartz crystals.

What appears to be an exceptional microscopic occurrence was noted in two thin sections of gray zinc carbonate ore from the Chrysolite dump. Here minute crystals were found in the middle parts of veinlets and as central fillings of certain vugs, in each veinlet bordered by smithsonite of the later stage. In a single thin section some vugs may be filled with smithsonite and quartz, and others with calamine with or without quartz. No explanation is offered to account for the failure of silica and zinc to combine in certain places when they did in others within an area not more than half an inch square.

Silica is also present in considerable amount with the iron oxide bodies in or adjacent to the zinc ores. As a rule this silica is completely concealed by the iron oxides, but in one thin section from the walls of a zinc stope on the Tucson first level it was found to be present as minute quartz grains mingled with the iron oxide and also as minute agate-like growths in microscopic vugs.

Microscopic quartz with sericite and sulphide grains has been seen in thin sections of gray zinc carbonate which has replaced manganosiderite. It was originally present in the manganosiderite and has escaped replacement.

Chert has been found in reddish-brown zinc ore at a few places, where it forms the only unreplaced remnants of the original limestone or dolomite.

¹ Hillebrand, W. F., and Penfield, S. L., Some additions to the alunite-jarosite group of minerals: *Am. Jour. Sci.*, 4th ser., vol. 14, p. 213, 1902.

SERICITE.

The only sericite noted in the oxidized zinc ores is the small amount which, with quartz and sulphide grains, was originally in manganosiderite and has escaped replacement.

KAOLIN.

Kaolin is present as an abundant constituent of the material that separates many lead carbonate stopes from zinc carbonate stopes. It is for the most part stained with iron or manganese oxides but has its typical white color in patches away from which the iron and manganese oxides have segregated. Kaolin is also present as the principal filling of strong fissures, one of which in the Maid of Erin mine was found to be bounded on both sides by oxidized zinc ore. This kaolin was also more or less stained by iron and manganese oxides and was practically identical in general appearance with the zinciferous clay ore but differed in its relatively low specific gravity. In thin section, as stated on page 25, it was found to contain a net work of streaks and patches of rather high birefringence, resembling sericite and also the zinciferous clay, its appearance suggesting that a small percentage of zinc had been introduced. A few small calamine crystals were also present in it.

At the base of a porphyry sheet in the Belgian mine was seen a kaolin mass which was stained bluish green by some copper salt. A low zinc content was also found in this mass, and it seems probable that the presence of both copper and zinc was due to adsorption by the kaolin.

SULPHIDES.

At several places in the Western Mining Co.'s workings (Pls. VII and VIII) the oxidized zinc ores have been found almost or quite in contact with bodies of sulphides, chiefly pyrite, but at no place examined by the writer could more than a small face exposure of sulphides be seen. The sulphides where exposed were clean and fresh and showed no evidence of having reacted with zinc solutions to produce secondary zinc sulphides.

In the winze about 180 feet north of the south end of the lower Maid of Erin ore body (Pl. VII) a small streak of galena was noted along a preserved bedding plane within a mass of brown zinc carbonate ore. Calamine crystals, abundant in the brown ore, were also present within the galena streak, filling cavities formed by the removal of either limestone or zinc blende.

Small amounts of sulphides were also noted in gray zinc carbonate ore. These sulphides were originally in manganosiderite but escaped

replacement. They were chiefly pyrite but included a few scattered grains of sphalerite (not wurtzite) and galena.

NATIVE SILVER.

The only occurrence of native silver noted was seen in a small stope on the Maid of Erin first level, at Crowell's raise. The silver formed small flakes and wires in a small mass of siliceous iron oxide veined and sprinkled with calcite about $1\frac{1}{2}$ feet in diameter which lay between an old lead stope above and a zinc stope below. The silver flakes for the most part were scattered through the iron oxide, but some were closely associated with visible spots of calcite.

PARAGENESIS.

The paragenesis of the minerals, or the order in which they were formed, may be summarized from the foregoing descriptions as follows:

Dolomite or magnesium limestone, manganosiderite, barite, chert, the quartz-sericite aggregates, and the sulphides existed before oxidation of the original ore bodies began. The iron oxide and kaolin masses that separate the lead carbonate from the zinc carbonate bodies may, from analogy with zinc deposits in other districts, have been the first of the oxidized minerals to form, but their origin in the Leadville deposits is not so clear. They may also be due in part to the leaching away of zinc minerals originally deposited with them. They will be further considered in the discussion of the genesis of the ores. The one occurrence of native silver noted was evidently formed at the same time as the iron oxide.

The first oxidized zinc ore mineral to form was the massive gray smithsonite, containing varying but considerable amounts of iron and manganese carbonate. This mineral replaced manganosiderite and dolomite (Blue and White limestone). It is believed to have formed at the same time as or immediately after the iron oxide and kaolin masses just mentioned.

Later, through oxidation, the iron and manganese present began slowly to oxidize, forming the red or brown iron oxides and the zinc-manganese oxide hetaerolite, with a corresponding amount of the later and purer drusy smithsonite, which, as shown in thin section, alternated with the iron oxide and the hetaerolite, suggesting a rhythmic alternation in deposition. The largest growths of hetaerolite, however, followed the drusy smithsonite. The inconspicuous growths of chalcophanite may be the result of the alteration of hetaerolite by further oxidation, or they may have been precipitated from solutions of different concentration from that which yielded the hetaerolite.

Oxidation of remnants of gray ore and manganosiderite is still in progress and doubtless has been to a greater or less extent ever since oxidation began.

Calamine and locally aurichalcite and zinciferous clay were next formed. The calamine in part was formed at the expense of smithsonite, leaving relatively pure residual iron oxide; in part it was deposited in fractures and vugs in both smithsonite and dolomite (limestone). Aurichalcite, as shown in thin section, was deposited at the same time as calamine. The zinciferous clay in some places appears to have been formed instead of calamine in the presence of alumina, as it bears the same relations to all the minerals of earlier growth. Where calamine and the zinciferous clay are present together, the calamine in some places forms the margins and the clay the middle fillings of veinlets. In the Belgian mine the clay forms the margins of pockets and a parallel growth of calamine and clay the central fillings, whereas in one specimen the calamine forms networks of veinlets through the clay. These differences may be attributed to varying conditions of chemical equilibrium; a relative excess of zinc over alumina may have caused calamine to represent the beginning of deposition in the first case, and a corresponding excess of alumina may account for the marginal growth of clay in the second; the calamine veinlets in the clay may be a decomposition product of the clay, or a deposit from solutions of a later stage which reached the previously dried and cracked clay. The small size and scattered distribution of these occurrences prevent the drawing of a definite conclusion regarding the relations between calamine and zinciferous clay.

Silica, either in an amorphous or a minutely crystallized condition, was deposited with or just after calamine and, in most of the specimens studied, appeared to represent the excess of silica over zinc in solution. The presence of aurichalcite with calamine and silica is interesting in this connection, suggesting a rather delicate balance between carbon dioxide and silica that allowed the formation of aurichalcite instead of additional calamine and the copper silicate, chrysocolla. The replacement of smithsonite by calamine in several places and the occurrence of smithsonite in contact with a later growth of quartz in at least one place (specimens from the Chrysolite dump) raise another question as to the conditions under which zinc silicate may form.

Calcite was distinctly the latest of all the common minerals of the oxidized zinc deposits, except, of course, iron and manganese oxides, which may still be forming. Its period of growth may have slightly overlapped that of calamine, but it is for the most part distinctly later. The exact position of aragonite and nicholsonite in the paragenesis can not be stated. Both have formed in pockets in iron or

iron and manganese oxides, but their relations to the different zinc minerals have not been ascertained.

VARIETIES OF ORE.

So far as appearance and differences in composition are concerned, four varieties of oxidized zinc ore may be distinguished, but these are so intimately associated that all may enter into a single carload. The four varieties are (1) gray carbonate ore, (2) reddish-brown to brown carbonate ore, compact or filled with calamine pockets, (3) brownish-black to black carbonate-oxide-silicate ore, and (4) white to brown dense silicate ore (zinciferous clay or "talc"). The brown varieties, Nos. 2 and 3, are by far the most abundant.

GRAY CARBONATE ORE.

OCCURRENCE.

Gray carbonate ore was noted at a few different places in the Maid of Erin mine and on the dump of the Chrysolite mine. At least two of the occurrences in the Maid of Erin were found immediately below pyritic sulphide ore. The others had not been developed, and their relations to other ores was not definitely known. An occurrence of grayish-brown to yellowish-brown ore on and below the Henriette fourth level, although not found immediately in contact with other ores, is doubtless below lead carbonate ore, as only lead carbonate ore has been found at so high a level in the vicinity. (See Pl. VII and section AA, Pl. VIII.) One of the deposits of gray ore contained an inclusion of manganosiderite, which had evidently escaped replacement. Further evidence of this replacement is given in the description of the microscopic features of the ore (pp. 37-38).

MEGASCOPIC FEATURES.

The ore is of medium to light gray color where quite free from oxidation, but some specimens show more or less yellowish-brown iron oxide stains in places, and by increase in the amount of staining the gray ore grades into the reddish-brown to brown variety. The texture of the gray ore is very fine grained to dense (microgranular) for the most part, but small cavities or vugs ranging from minute pores up to holes an inch or two in diameter are irregularly scattered through it. In places these cavities are small enough and regularly enough distributed to suggest shrinkage accompanying replacement of the original rock; in others they appear to be enlargements of fractures; and in still others they are clearly the result of the leaching out of the more permeable portions of the ore. Cavities of the first two kinds have rounded edges where the carbonate ore

has developed microscopic drusy surfaces. Those of the last kind have rough, corroded surfaces. No minerals of megascopic size were seen in the fresh gray ore, except a few specks of pyrite, zinc blende, and possibly galena, which were noted in two specimens. These sulphides occur in minute veinlets and scattered grains, just as they do in the manganosiderite. In the brownish-gray partly oxidized ore from the Henriette workings the fine-grained carbonate aggregate is traversed by veinlets of calamine.

MICROSCOPIC FEATURES.

In thin section (Pl. II, *A*) the gray carbonate ore is composed mostly of a uniform aggregate of very fine carbonate grains of high relief, typically high birefringence, and cloudy appearance. This aggregate is cut by veinlets of smithsonite that are characterized by a somewhat coarser grain and freedom from cloudiness. Smithsonite, optically similar to that in the veinlets, also forms minute rhombohedrons lining small cavities. A few minute diverging aggregates and single grains of calamine were noted filling small cavities, but the total amount is negligible so far as the amount of zinc in the ore is concerned. Incipient oxidation is marked by faint brown and black stains of iron and probably manganese oxides. A veinlet of calcite, distinguished from smithsonite by distinctly lower index of refraction, was noted.

The ore incloses small veinlets and patches consisting of varying proportions of quartz, sericite, pyrite, and locally zinc blende and galena. It also incloses scattered single grains of the same minerals. Many of these inclosed veinlets have a marked "wriggling" shape. Some are distorted and even appear to have been pulled apart. Some are penetrated or cut by veinlets of smithsonite. Small aggregates of pyrite also appear to have been pried apart by smithsonite veinlets. The quartz-sericite-sulphide veinlets and aggregates have the same features, except for the distortions just described, as in the manganosiderite and are evidently all that is left of the manganosiderite body originally present.

Under high magnification the fine aggregate proves to be composed of countless anastomosing rows of clear, transparent granules inclosing small rounded bunches of clouded (more strongly absorptive?) granules. The anastomosing rows are so arranged as to indicate the outlines of former manganosiderite grains. In some thin sections the small clouded bunches have been removed by leaching and, perhaps, in part during grinding of the section, leaving a porous mass of anastomosing rows of smithsonite. These pores may also be in part due to removal of grains or minute aggregates of quartz, sericite, and

pyrite, but removal of these minerals certainly can account for only a minor part of the entire pore space. As this finely porous texture has been noted in specimens as well as thin sections, there is no doubt that it has resulted mainly from leaching.

This anastomosing structure indicates that the zinc solutions permeated the manganosiderite (or dolomite in some places) along the boundaries of grains and replaced the grains from their margins inward. The replacement was not strictly pseudomorphous, as the texture of the ore is markedly finer than that of the manganosiderite, even including the clouded bunches of granules inclosed among the anastomosing grains. An attempt to prove the assumption that the clouded bunches have stronger absorption and are therefore probably higher in iron than the anastomosing portions was unsuccessful, owing to the extremely fine grain of the ore.

If manganosiderite corresponding to analysis 1 (p. 47) was completely replaced by gray zinc carbonate ore corresponding to analysis 2, the replacement should have been accompanied by about a 15 per cent shrinkage;¹ but evidence of shrinkage is obscured by different factors other than the effects of partial leaching of the ore. The recrystallization that accompanied replacement may have distributed the amount of shrinkage so as to render it inconspicuous, or it may have readjusted the material so that shrinkage was expressed by numerous small fractures. The fractures in the ore, whether due to shrinkage or to other causes, are now filled with the smithsonite veinlets, which may represent material recrystallized practically in place, or additional material introduced after the direct process of replacement had practically ceased. Furthermore, deposition of the smithsonite veinlets appears to have caused expansion in certain places. The conclusion that the theoretical amount of shrinkage took place rests on the assumption that the zinc was introduced as some salt, presumably sulphate, which could react with manganosiderite (or dolomite) and deposit an amount of zinc carbonate exactly equivalent to the amount of manganosiderite replaced. It is probable that the zinc was largely introduced as sulphate, but the veinlets of second-stage smithsonite show that a part of it was introduced as carbonate and that deposition was not entirely the result of simple molecular interchange. The amount of shrinkage can therefore not be determined from the porosity of the ore in its present state, nor can it be closely estimated from the texture and structure of the ore.

¹ Specific gravities were not determined, as the zinc ore is much more porous than the manganosiderite. Porosity was not determined, as the pores and other cavities in the ore are obviously due in part to other causes than shrinkage. Published specific gravities of the several carbonates represented in the analyses vary according to impurities, and 15 per cent shrinkage is an approximate average based on these varying data. Theoretically the shrinkage may have amounted to as much as 17 or 18 per cent.

CHEMICAL COMPOSITION.

The chemical composition of the gray ore is shown by analysis 2 (p. 47), made by R. C. Wells, of the United States Geological Survey, from material collected in the narrow stope on the first intermediate level above the second in the Maid of Erin mine, about 100 feet south of the New Maid (Maid Combination) shaft. The ore lay beneath a sulphide body and contained small stringers of sulphides; but these were avoided in the material analyzed, as were portions showing brown or black stains.

The silica and alumina in this analysis represent quartz and sericite, which together amount to about 2 per cent. The total absence of ferric oxide (Fe_2O_3) is noteworthy when this analysis is compared with analyses 3 and 4, of brown zinc ores. The ferrous oxide, magnesia, lime, manganese oxide, and zinc oxide are present as carbonates, but the total of their molecular ratios is a little in excess of the total carbon dioxide. If the excess is placed wholly in the manganese oxide, there remains an excess of 0.2 per cent, which is decidedly high in view of the color and microscopic composition of the material analyzed. No trace of any mineral containing phosphorus was noted, and the phosphorus pentoxide (P_2O_5) can not be definitely accounted for. If it were combined with enough lime to form apatite, a corresponding reallocation of carbon dioxide (CO_2) would almost balance the excess of manganese oxide (MnO); but this arrangement would demand the presence of 0.67 per cent apatite, whereas none was found in thin section. The water driven off above 110°C . ($\text{H}_2\text{O}+$) is also in excess over the amounts necessary to enter into sericite and possible hydrous manganese oxide, and the excess is interpreted as being so intimately inclosed in the ore that it is not driven off until temperatures above 110° are reached. In this connection it is interesting to note that all the P_2O_5 and more than half the $\text{H}_2\text{O}+$ shown in the manganosiderite analysis are in similar excess. Their presence both before and after replacement implies that they, like the quartz and sericite, were not affected by the solutions that introduced the zinc.

The approximate mineral composition of the gray ore, based on microscopic study and the chemical analysis, is as follows:

Carbonates:		Sericite	0.8
ZnCO_3	76.5	Excess MnO	.2
FeCO_3	14.5	Excess P_2O_5	.3
MnCO_3	3.2	Excess $\text{H}_2\text{O}+$	.9
MgCO_3	1.0	Excess $\text{H}_2\text{O}-$	.5
CaCO_3	.5		
Quartz	1.1		99.5

If the carbonates are recalculated to 100 per cent, and the carbonates of the manganosiderite are similarly recalculated from analysis 1, the following comparative results are obtained:

Recalculated composition of manganosiderite and gray zinc ores.

	Mangano- siderite.	Gray ore.	Differ- ence (per cent).
ZnCO ₃		79.88	+100.0
FeCO ₃	51.49	15.14	- 70.6
MnCO ₃	38.15	3.36	- 91.2
MgCO ₃	10.12	1.06	- 89.5
CaCO ₃.....	.24	.56	+ 57.1
	100.00	100.00	.....

The percentage differences—that is, the gain or loss of the different constituents during the replacement process—are given in the third column, which shows that manganese and magnesia were very largely removed in nearly equal proportions, whereas iron was removed in less but still very considerable amount. The increase in calcium carbonate is attributed to the presence of a few microscopic veinlets in the gray zinc ore. The chemistry of replacement is considered further in the discussion of the genesis of the ores (pp. 68—85).

BROWN CARBONATE ORES.

MEGASCOPIC FEATURES.

The brown carbonate ores vary considerably in character. In some places they are hard and compact, without conspicuous vugs or with only very small vugs lined with fine druses of smithsonite (Pl. III, *A*); in others they are softer and may be filled with vugs of varying size lined or nearly filled with white calamine (Pl. IV, *A*). Their color ranges from chocolate-brown to dark brick-red. The only minerals of megascopic size are present in vugs and veinlets. As a rule, where the vugs are small and relatively scarce, they are lined with fine druses of second-stage smithsonite, which may alternate with films of hetaerolite or iron oxide. In the larger vugs similar linings of smithsonite are covered by typical growths of calamine, or in places by exceptionally large growths of hetaerolite or chalcophanite (Pl. I, *B*), which in turn may be covered by calamine. Aurichalcite may accompany the calamine, as in the Ibex mine. (See Pl. V, *B*.)

The compact body of the ore is not to be distinguished at first glance from much of the iron ore or iron-stained manganosiderite, dolomite, or limestone. It may be of uniform brown color or may be spotted with stains of black manganese oxide (hetaerolite?). In

some places it preserves rather thin bedding planes and breaks into layers; in others it has a marked conchoidal fracture. It may be hard, or it may be soft and crumbly. Although compact brown zinc ore even of rather low grade may be readily distinguished from iron-stained dolomite or limestone by its higher specific gravity and finer grain, it can not be so distinguished from dense forms of iron ore. Again soft porous ore can not in some places be surely distinguished from either porous iron ore or decomposed wall rock, owing to the relatively light specific gravity of all three materials. Calamine growths in vugs are not an absolutely sure indication of good ore, as one of two samples of similar appearance may prove to be excellent ore and the other to be of too low grade to ship. The latter variety is due in part to a leaching of the brown carbonate to form the silicate, or to the deposition of calamine in cavities of stained and partly decomposed limestone. In one sample the soft brown material around the calamine pockets was found by Mr. Wells to contain only 14.1 per cent of zinc oxide (11.3 per cent of zinc), which on close inspection proved to be largely in the form of minute calamine crystals that had grown within the porous mass. Nearly all the zinc carbonate had been leached, and almost the entire zinc content of the material was contained in the calamine druses. In other specimens, where the carbonate ore was not leached and the calamine was introduced from elsewhere, the value of the ore, already of good grade, was increased.

Of the many specimens of compact ore collected, one, said to represent ore containing 22 per cent of zinc, proved on microscopic study to be composed almost entirely of iron oxide and silica. Another, which was said to contain 30 per cent of zinc but whose texture gave it a close resemblance to the altered manganosiderite that borders some of the ore bodies, was found by George Steiger to contain 50.69 per cent of zinc oxide (40.72 per cent of metallic zinc), 2.38 per cent of insoluble (probably quartz and sericite), only 0.63 per cent of magnesia, and no lime. The specimen had a rather high specific gravity, but that could easily have been attributed to iron originally in manganosiderite.

The brown ore may include small bodies, patches, or seams of the zinciferous clay colored by a small amount of iron oxide. This clay may be distinguished from the brown carbonate by its characteristic properties described on pages 24-28.

Where the original bedding is preserved, thin streaks or bunches of calamine are distributed along the bedding planes and also along short cross fractures that connect bedding planes, as shown in figure 2. This distribution of the calamine, which is well exhibited at several places in the Maid of Erin mine, is of interest in showing the courses followed by the zinc-bearing solutions, which evidently

percolated along bedding planes, cross joints, and minor (microscopic) fractures and were thus able to react uniformly throughout a body of great horizontal and vertical extent. The process was evidently entirely metasomatic at first, and any resulting shrinkage may have served to widen the openings along bedding planes and fractures, and perhaps also to develop new contraction fractures, thus allowing percolation of additional solution through already replaced rock to lower levels and affording openings for the deposition of second-stage smithsonite and calamine. The gradation of linear fracture fillings of calamine into vugs, especially at junctions of fractures with one another or with bedding planes, points to the

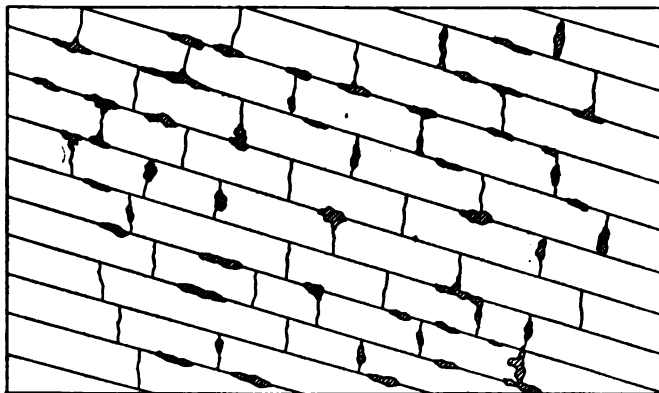


FIGURE 2.—Diagram showing distribution of calamine along bedding planes and cross fractures in brown zinc carbonate ores.

origin of the vuggy ore as the extreme development of the structure just described—crisscross fractures and bedding planes having enlarged into vugs, and the smithsonite having been more or less converted into calamine.

A few vugs have evidently resulted from replacement by smithsonite only along the immediate walls of fractures and the subsequent removal of the unreplaced rock, leaving a cellular ore which is usually of very good grade. Material of similar appearance, however, has been found to be composed chiefly of silica and iron oxide.

MICROSCOPIC FEATURES.

In thin section the brown carbonate ore consists of a very fine, even-grained aggregate of carbonate grains stained by iron oxide but with many microgeodes lined or filled with transparent carbonate grains. (See Pl. III, *B*.) The transparent grains under high magnification show characteristic acute rhombic terminations. Some of them appear pure, some of them have zonal inclusions (or alternating growths) of black manganese oxide (hetaerolite?), and

others have similar inclusions of brown iron oxide. The last two occurrences indicate a breaking down of the ferruginous gray zinc carbonate of the first stage and its recrystallization as purer smithsonite of the second stage and iron or manganese oxides. Some of the vugs of second-stage smithsonite are surrounded by what appears to be pure iron or manganese oxide, a relation which also points to a breaking down of the impure zinc carbonate of the first stage, accompanied by segregation of the different products. Throughout the mass of the ore the iron and manganese oxides show this tendency to segregate, the iron oxide having a weak tendency to form a network of hairlike veinlets and the manganese mineral a much stronger tendency to gather into spots or to fill distinct fractures.

The relations of the calamine to the rest of the ore may be illustrated by two contrasted examples. In one a small group of diverging calamine crystals filling a vug was seen to be surrounded by iron oxide, which was opaque except along the edges of the vug, where it formed translucent pseudomorphs after acute smithsonite rhombs. Here the zinc in the calamine was evidently formed largely in place at the expense of smithsonite. In the other example a calamine veinlet cut through a black spot of manganese oxide, proving that it was formed after the breaking up of the impure first-stage carbonate ore was well advanced; but there was no uniform accumulation of iron or manganese oxides along the vein, and the margins of the vein were lined with clear smithsonite rhombs. Inclusions of brown carbonate ore in the vein showed no evidence of leaching. The calamine, therefore, must have been wholly deposited by infiltrating solutions.

One thin section of a specimen of brown ore, taken beneath a sulphide body and very near a mass of gray carbonate ore that contained an inclusion of manganosiderite, is of especial interest in showing the relation of the brown to the gray ore. This section contained within the typical fine-grained carbonate a relatively coarse grained remnant having a texture quite like that of the manganosiderite but showing a relatively weak absorption, presumably due to partial or complete oxidation of the iron. The same section contained quartz-sericite veinlets in both the gray ore and the manganosiderite, and there seems no occasion to doubt that the brown ore at this place is the oxidized product of the gray ore.

The great extent and uniformity of oxidation of the brown ore is a striking feature, as the few small bodies of gray ore appear to be the only remnants of the original zinc carbonate ore that have escaped oxidation. The ore as a whole must have been easily and uniformly permeable by oxygen, a character which indicates a very finely porous structure. It may be suggested that the porosity was

developed during replacement of the original rock by gray zinc ore, but are already pointed out (p. 38) the factors influencing porosity in the present gray ore are too varied and opposite in their effects to permit a definite conclusion on this point, and the effects of oxidation add one more obstacle to its determination in the brown ore.

CHEMICAL COMPOSITION.

In the light of microscopic evidence chemical analyses of the brown ores are not difficult to interpret. In the table on page 47 analysis 3 represents the sample of high-grade ore from the Maid of Erin mine which contains the microscopic quartz-sericite veinlets above mentioned and is clearly an oxidized product of gray ore, and analysis 4 an ore of lower grade beneath a Gray porphyry sheet and between walls of dolomite (Blue limestone), from the first level of the New Dome No. 2 mine. Sample 3, in comparison to the gray zinc carbonate ore, represented by analysis 2, contains a larger amount of quartz and sericite. It also contains considerably more iron, and the iron is completely oxidized to the ferric state. Magnesia and lime are each a little higher, whereas zinc oxide and carbon dioxide are correspondingly lower. The absence of phosphoric acid is noteworthy, suggesting its removal in solution during the oxidation and breaking down of the gray carbonate ore. In the material for analyses 2 and 3 calamine druses were avoided. As the irregular distribution of calamine and of iron and manganese oxides renders strictly representative analyses out of the question, the determinations are only made to tenths of 1 per cent.

The calculated mineral composition of the ore represented by analysis 3 is as follows:

Carbonates:		Quartz	2.9
ZnCO ₃	71.3	Sericite	2.5
FeCO ₃	0.0	Limonite	15.7
MnCO ₃	3.0	Excess MnO	1.1
MgCO ₃	1.3	Excess H ₂ O+	.1
CaCO ₃	.7	Excess H ₂ O—	.9
			99.5

The excess MnO and H₂O+ are present as black oxide, which is probably hetaerolite, but as the formula of that mineral is in doubt (p. 23) no attempt is made here to estimate its small percentage. Comparison with the mineral composition of the gray ore (p. 39) shows that whereas all the iron has been oxidized, the manganese remains mostly as carbonate. The magnesia and lime carbonates also have remained unaffected during the process of oxidation.

Analysis 4 represents an ore of lower grade and one deposited under somewhat different conditions. The ores represented by analyses 2 and 3 were deposited directly beneath sulphides, by replacement of manganosiderite, but that represented by analysis 4 was deposited directly beneath Gray porphyry, by replacement of dolomite (Blue limestone). The ore is of dark-red color and is too soft to permit the grinding of a thin section, but it contained small vugs of drusy smithsonite and calamine, and so far as could be seen, the only essential difference between it and sample 3 was the presence of a small amount of light-brown zinciferous clay. The silica and alumina in the analysis are accounted for by calamine and zinciferous clay. The ferric oxide is much greater than in analysis 3 and indicates either that the waters which introduced the zinc carried a great excess of iron or that the ore was deposited by different solutions, one, carrying the zinc and some iron, migrating along the bedding planes of the Blue limestone, and another, carrying iron but little or no zinc, working downward through the overlying porphyry. (See fig. 5, p. 55.) The impossibility of learning the exact geologic conditions surrounding this deposit leaves the matter in doubt. The softness of the ore suggests that there has been a downward leaching of zinc, but hard ore directly below the soft contains no more than 30 per cent of zinc, and mere leaching of zinc is far from enough to account for the excess of iron. Another explanation is that after zinc carbonate ore had been formed ferric sulphate solutions, with excess of acid derived by decomposition of pyrite, could redissolve the zinc carbonate, and after they had become neutralized the ferric sulphate in them could become oxidized and be deposited as ferric oxide. The dissolved zinc carbonate could be transferred downward through the ore and replace the dolomite walls, thus extending the original lower limit of the ore body. This hypothesis could also be applied in explaining the layers of iron oxide that are commonly found between lead carbonate and zinc carbonate stopes.

The magnesia in analysis 4, though low, is about three times as high as in analyses 2 and 3, an excess corresponding approximately to the proportional difference between the magnesia in dolomite and in the manganosiderite represented by analysis 1. The lime, however, is quite as low as in analyses 2 and 3, although its difference in the two rocks replaced was decidedly greater than that of magnesia. Manganous oxide is somewhat greater than in analysis 3, but little significance can be attached to the difference, owing to the irregular distribution of manganese oxide stains. The zinc oxide, though much lower than in analyses 2 and 3, is in excess over the available carbon dioxide. The excess, as will be shown presently, in the calculated mineral composition, indicates the proportion of calamine and zinciferous clay present. The higher percentage of combined

water ($\text{H}_2\text{O}+$) is insufficient to hydrate all the large amount of ferric oxide to the composition of limonite. The absence of phosphoric acid, in contrast to its presence in analysis 2, is again noteworthy.

The following calculation of the mineral composition of the ore is less satisfactory than those made from the other analyses, owing to the indefinite composition of the zinciferous clay and the uncertainty of the exact formula for hetaerolite:

Carbonates:		Kaolin.....	5.9
ZnCO ₃	37.5	Calamine.....	5.0
MgCO ₃	3.6	Excess ZnO.....	2.4
CaCO ₃.....	.5	Excess MnO.....	3.3
		Limonite.....	15.3
		Hematite.....	24.2
		H ₂ O.....	1.7
			<hr/>
			99.4

The kaolin and calamine are of course arbitrarily separated. A little calamine is undoubtedly present, but how much of the calculated calamine is in reality present as zinciferous clay is not known. The excess zinc oxide is for the most part accounted for by the reasonable assumption that all the manganeous oxide is present as hetaerolite, but there is a small excess (nearly 0.6 per cent) of zinc oxide over the $\text{ZnO}:\text{Mn}_2\text{O}_3$ ratio demanded by either of the proposed formulas for hetaerolite, and this excess may also be regarded as belonging to the zinciferous clay. The total absence of manganese carbonate can not be proved, but in view of the relatively low carbon dioxide any error in the assumption that all the manganese is oxidized is negligible. The iron oxide is figured so far as possible as limonite, for convenience in comparison with the other analyses, and the excess of iron oxide over water is recorded as hematite. The ratio of water to iron oxide is slightly in excess of that for turgite ($2\text{Fe}_2\text{O}_3\cdot\text{H}_2\text{O}$). The red color indicates the presence of a considerable amount of either hematite or turgite.

BLACK ZINC ORE.

The black or brownish-black zinc ore is found only in small quantity and varies considerably in composition. In part it is essentially of the same character as the brown vuggy ore, except for its greater content of a black manganese oxide, which in some specimens has the crystalline structure of hetaerolite or chalcophanite. The vugs are commonly lined with calamine, and some cellular specimens may be found consisting almost entirely of calamine and hetaerolite or

hanite, accompanied by a small amount of iron oxide. This oxide variety of black ore is clearly derived from the carbonate ore. Other samples of black ore are composed chiefly of zinc-clay stained black by a manganese oxide. The occurrences of variety seen by the writer were all said to be of low grade. Specimens of the black ore, especially of the silicate-oxide variety, whether of high or low grade, are likely to have a surprisingly low specific gravity, owing to their vuggy or very porous character. No chemical analyses of the black ore were made, as they would serve only to show to what extent manganese and silica had been locally condensed and carbon dioxide eliminated.

WHITE OR "TALCY" ZINC ORE.

zinciferous clays, described on pages 24-28, may occur in large enough to be considered ore bodies. It is questionable whether they could be smelted at a profit.

ANALYSES.

The following table are given chemical analyses of the more important varieties of zinc ore discussed above:

Analyses of zinc carbonate ores.^a

	1	2	3	4
.....	10.08	1.5	4.1	4.0
.....	3.16	.3	1.0	2.3
.....	None.	.....	13.4	36.9
.....	26.80	9.0	.....	.....
.....	4.04	.5	.6	1.7
.....	.08	.3	.4	.3
.....	19.71	2.2	3.0	3.3
.....	Undet.	49.6	46.2	30.2
.....	Undet.	.....	.....	.....
.....	Undet.	.....	.....	.....
.....	33.14	34.4	27.2	15.3
.....	.47	.3	.....	.....
.....	Undet.	.....	.....	.....
.....	Undet.	.....	.....	.....
.....	.80	1.0	2.5	3.8
.....	.22	.5	.9	1.7
.....	.57	Undet.	Undet.	Undet.
.....	.08	Undet.	Undet.	Undet.
.....	Trace.	Undet.	Undet.	Undet.
.....	Trace.	Undet.	Undet.	Undet.
.....	.84	Undet.	Undet.	Undet.
zinc.....	100.08	99.6	99.3	99.6
		39.9	37.1	24.2

^a U. S. Geol. Survey Bull. 591, p. 240, 1915.

malachite, seventh level Tucson mine (collected by J. D. Irving). J. G. Fairchild, analyst.
 yellow zinc carbonate ore, Maid of Erin mine, first intermediate above second level. R. C. Wells,
 brown zinc carbonate ore, Maid of Erin mine, "high line" level. R. C. Wells, analyst.
 light zinc carbonate ore, New Dome mine, first level (at No. 2 shaft). R. C. Wells, analyst.

RANGE IN METAL CONTENT OF THE ORES.

ZINC CONTENT.

The zinc content of the ores varies greatly from place to place. In some stopes bodies running over 40 per cent of zinc have been mined, and many others, especially in the Carbonate Hill workings, have yielded much ore averaging 30 per cent of zinc. In fact, up to the end of 1913 the Western Mining Co.'s great shipments did not run below 28 per cent. These high-grade bodies, however, are bordered and separated by large quantities of lower-grade ore, averaging about 20 per cent of zinc, and these in turn may grade into iron ore or altered dolomite, in which the percentage of zinc drops to practically nothing. In some places the transition from pay ore into low-grade material is gradual; in others, pay ore is rather sharply bounded by unaltered rock, an altered zone a few inches or a foot or two in thickness separating the two.

In some places it is a rather easy matter to distinguish between ore and waste, but in others distinction is possible only after frequent and careful sampling. Two of the most influential factors causing this difficulty are the varying degree of porosity and the varying though usually considerable percentage of iron in the ore. Some high-grade ore closely resembles altered manganosiderite or dolomite in color and texture, but its microscopic porosity would lead to an underestimate of its zinc content. Another sample of similar appearance and approximately equal specific gravity may prove on analysis to contain a large amount of iron, either as ferrous carbonate or as ferric oxide. Some brown zinc ores of moderate to high grade may be practically identical in appearance with very low grade zinc ore, or even to iron and iron-manganese ores. High-grade brown vuggy ore with calamine druses may have the same appearance as leached brown earthy material with similar druses. Considerable experience may give the ability to detect inconspicuous though critical differences between ore and waste, but the principal result of experience tends rather to make one more cautious than ever, and to depend on frequent sampling and assaying as the only reliable means of distinguishing ore from waste.

This question of the grade of the ores was experimentally investigated by Butler,¹ who analyzed and determined the specific gravity of nearly 50 specimens and found that they all absorbed water slowly, but at varying rates, for many hours. In order to procure comparable data, he allowed particles weighing about 1 gram to soak 15 minutes before weighing, his determinations thus representing the specific gravity of the samples with their pores nearly filled with

¹ Butler, G. M., *Econ. Geology*, vol. 8, pp. 14-15, 1913.

air. He states that in consequence of these and many other tests, it can be said that an ore with a specific gravity of less than 3.3 as determined in this way is in all probability of too low grade (under 27 per cent) to be mined profitably when the market price of zinc averages about 5 cents a pound, as it did during the greater part of 1913, when Butler's paper was written. The following table gives the results of Butler's determinations, together with calculated specific gravities of seven of the samples based on chemical analyses:

Data on oxidized zinc ore of various grades from Leadville.

Ore.	Per cent of zinc.	Observed specific gravity.	Calculated specific gravity.	Effervescence in dilute hydrochloric acid.
1. Light gray, granular, with cavities; considerable pyrite and other sulphides visible.	17.7	3.5	3.8	Very slight.
2. Reddish brown, earthy.....	20.9	2.7	3.6	Vigorous.
3. Reddish brown, earthy, with cavities.....	22.4	2.7	.....	Do.
4. White, finely granular, compact to earthy.....	23.7	2.9	3.6	Considerable.
5. Brown, cryptocrystalline; many cavities lined with druses of smithsonite crystals, some of them underlain with psilomelane.	30.4	3.8	.....	Do.
6. Light gray, very finely granular, cavernous, a few druses of scalenohedral calcite.	31.4	3.9	.....	None.
7. Dark brownish-red, cryptocrystalline; many cavities with druses of smithsonite crystals; some psilomelane and calamine.	31.5	3.9	.....	Considerable.
8. White, with a brownish tint, very finely granular, with a spongy appearance; microscopic drusy cavities.	32.4	3.9	.....	None.
9. Same as No. 7 but contains no calamine or psilomelane.	32.7	3.9	4.0	Considerable.
10. Same as No. 5.....	38.4	4.0	4.1	Very slight.
11. Yellowish brown, microscopically spongy to very finely granular and compact.	41.6	3.9	4.1	Considerable.
12. Brown and white, cryptocrystalline to earthy, with a cavernous appearance; cavities wholly or partly filled with calamine.	45.4	3.7	.....	Do.
13. Same as No. 12 except that some hydrozincite is recognizable.	45.4	3.9	.....	Do.
14. Yellowish brown, very cavernous, with thin, plane walls.	46.0	3.9	.....	Very slight.
15. Light yellowish brown, finely granular, cavernous....	46.4	4.0	4.2	Considerable.

Butler's analyses of seven of these samples are given in the following table:

Analyses of oxidized zinc ores from Leadville.

	1	2	4	9	10	11	15
Zinc.....	17.7	20.9	23.7	32.7	38.4	41.6	46.4
Lime.....	.8	.3	.6	.3	.4	.3	.9
Magnesia.....	.8	1.1	.7	2.2	2.0	.4	.5
Silica.....	4.0	22.4	33.6	3.3	3.8	8.7	.9
Iron.....	17.0	14.7	5.4	12.2	5.1	3.5	2.2
Sulphur.....	.6	.....	.....	.....	.....	.....	.....
Alumina.....	.4	2.2	2.8	.4	.2	.2	.2
Manganese.....	11.2	2.1	2.0	.....	6.0	2.8	.....
Insoluble.....	4.4	24.8	34.6	3.8	4.2	9.0	2.2

Sample 1 is evidently a partly replaced manganosiderite and has a specific gravity nearly as high as those of the high-grade samples. The other low-grade specimens show a much greater discrepancy

between observed and calculated specific gravities than the high-grade ores and evidently possess a much higher degree of porosity. The relation between specific gravity and the zinc percentage in the high-grade samples, however, shows that specific gravity is not a closely accurate indication of the grade of ore.

The degree of effervescence of fragments in dilute hydrochloric acid (3 parts water to 1 of acid), as determined by Butler, is given in the first table on page 49 and, as he states, is not of much avail as an indication of the grade of ore. Similar tests by the present writer confirm those of Butler. Gray zinc carbonate ores, which contain considerable amounts of iron carbonate, and also the manganosiderite yield little or no effervescence, as shown by samples 1, 6, and 8. Even when partly stained by oxidation, they effervesce very slightly. In the more thoroughly oxidized samples, where fine drusy or second-stage smithsonite is abundant, effervescence is more pronounced.

Blowpipe tests by Butler on all grades of the material yielded similar results, regardless of the percentage of zinc, low as well as high grade ores giving the characteristic sublimate of zinc oxide.

In concluding his discussion of the grades of the ores, Butler outlined the following method for quick determination of the grade:¹

Probably the simplest method for quickly ascertaining the approximate grade of oxidized zinc ore is to place about a teaspoonful of the finely powdered material to be tested upon a piece of iron or steel barrel hoop, $1\frac{1}{2}$ to 2 inches in width. This charge should be introduced into the incandescent coals of a blacksmith forge which has been blown until little black smoke is evident. The iron should be sunk into a depression in the glowing coals so that they stand a half inch or so above the sample on all sides. Then the draft should be increased until the iron is heated white hot. Oxidized zinc ore will take fire at this point, burning with a bluish flame and emitting white fumes of zinc oxide. The density of these fumes varies with the grade of the ore. Experience enables one to judge within 5 per cent of the zinc content by this method, which, although long known and practiced in some places, is unfamiliar to those in other localities. The scheme can be applied to ore of any grade, as material assaying 5 per cent zinc will yield visible fumes.

OTHER CONTENTS.

If the percentages of zinc oxide and carbon dioxide are subtracted from analyses 2, 3, and 4 on page 47, and the remainder recalculated to 100 per cent, the iron oxides will range from 50 to over 65 per cent. The residues, therefore, after extraction of the zinc become possible iron or mangiferous iron ores. The content of silver in each of the ores analyzed is less than 0.001 per cent. As 1 ounce per ton of 2,000 pounds equals 0.0034 per cent, it is doubtful whether the residues from ores corresponding to these analyses would contain enough

¹ Op. cit., p. 17.

silver to pay for its extraction. Although these samples analyzed are believed to represent typical oxidized zinc ores of the district, there may be exceptions, for it has been stated that early shippers of rich silver ore appear to have purposely broken the zinc ore in some places.¹

DISTRIBUTION AND MODE OF OCCURRENCE OF THE ORES.

GEOGRAPHIC DISTRIBUTION.

Oxidized zinc ores have been found in practically all the hills of the district, as far east as the Resurrection mine, near the head of Evans Gulch, and as far south as the Continental Chief mine, at Weston Pass, 9 miles south of Leadville. Thus far, however, although extensive low-grade bodies have been reported from several places, all the high-grade deposits in the other hills have proved very small in comparison with the immense bodies in Carbonate Hill.

DISTRIBUTION WITH RESPECT TO KINDS OF COUNTRY ROCK.

The oxidized zinc ore bodies thus far found are limited to the horizons of the two limestones. The small bunches of red siliceous zinc material found in fissures cutting a porphyry sill in the Belgian mine are the only deposits noted that were not within or along a contact of one of the limestones. Porphyry and quartzite in different places form rather sharply defined roofs or floors to ore bodies of considerable size.

RELATIONS TO THE DIFFERENT KINDS OF LEAD CARBONATE AND MIXED SULPHIDE ORE BODIES.

The ore bodies thus far worked are all closely associated with blanket bodies of lead carbonate ore. For the most part the zinc bodies underlie the lead bodies, but in some places they have replaced the same strata, either down the dip or even along the strike. Those in the Ibex No. 1 (Little Johnnie), although they are in the vicinity of lode fissures and magnetite-pyrite bodies, are immediately associated with old blanket stopes. The only apparent reason to account for this association is that the lode fissures and magnetite-pyrite bodies in this vicinity have not as a rule been subjected to oxidation, and their original zinc content accordingly has not been removed to form a body of oxidized ore. The Luema vein contains a considerable quantity of zinc blende, and as its upper part is oxidized, a corresponding quantity of oxidized zinc ore could be expected somewhere along the vein, below the level of oxidation. None, however, has been

¹ Eng. and Min. Jour., Feb. 14, 1914, p. 396.

found, and the only apparent explanation is that the strong kaolin ("talc") selvages along the vein have prevented any considerable quantity of zinc solutions from penetrating into the limestone walls. It is also possible that the great amount of kaolin has absorbed the meager amount of zinc from the solutions, giving rise to zinciferous clay; but this point has not been tested.

One feature that is of great annoyance to miners and prospectors and is difficult to explain satisfactorily is the lack of uniformity in the relations between the oxidized zinc bodies and the associated blanket lead bodies. At the north end of Carbonate Hill large bodies of both have been mined, but in Fryer and Iron hills, where large blanket deposits of lead ore have been mined, only small bodies of zinc ore have thus far been found among a great amount of iron-stained "contact matter," and some of these bodies have not been of very high grade. In some places, although blanket lead stopes are of considerable size, associated zinc ore has been found only in small bunches from a few inches to 3 or 4 feet in diameter.

The causes of this variation are probably several and can be best discussed in connection with the genesis of the ores. (See pp. 68-85.) It may be stated here, however, that the size of a zinc body depends on the amount of zinc in the original ore body, the kind and distribution of openings through which the waters transferring the zinc had to pass, the composition and texture of the rocks through which the waters passed, and the materials that accompanied the zinc in solution. Consideration of these factors, in places where the zinc ores have been mined or searched for, may yield a satisfactory explanation; but without a knowledge of them it is impossible to make a definite prediction as to the size and position of oxidized zinc bodies that may be associated with old blanket bodies of lead carbonate.

As none of the old blanket stopes were accessible to the writer, predictions regarding the location and extent of undiscovered bodies are not warranted here. It may be said that the amounts of "vein matter" shown in the cross sections by Emmons¹ suggest the probable presence of good oxidized zinc bodies in the northern part of Carbonate Hill other than the bodies already worked and of good-sized bodies on other hills; but experience in Fryer and Iron hills proves that the thickness and extent of "vein matter" shown in Emmons's sections are far from being good indicators of the amount of zinc ore present.

In two places noted by the writer bodies of oxidized zinc ore of rather low grade are not closely associated with old lead-silver stopes. In the Cord Mining Co.'s workings (Page lease, 1913) a small body of red zinc carbonate ore has been mined, which is 150 to 200 feet away (down the dip) from the nearest known lead-silver stope of

¹ U. S. Geol. Survey Mon. 12, atlas, 1886.

PLAN (A)

Belgian Shaft
Elevation of collar
10,576.3'

Elev. 10,354'

Elev. 10,485'

Belgian tunnel

80° fissure on level D

80° fissure on level B

Up

Old stope mined in early eighties

North line
LOUISVILLE

Belgian South line

Flagstaff drift

To Mt. tunnel

LEGEND

Level A ——— Old stope level (exact elevation not known)

Level B ——— 170 feet above Yak tunnel level

Level C - - - - - 160 feet above Yak tunnel level

Level D ===== 131 feet above Yak tunnel level

===== Yak tunnel level (elevation 10,354 feet)

80° Fissure

(B) SECTION ALONG LINE A-A'

Blue limestone overlain by 175' of white porphyry
Land 150' of water

Gray porphyry

Blue limestone

Parting quartzite

White limestone

Old lead carbonate stope, approximate

Old stope

Elev. 10,485'

Lower grade zinc at south end of drift

Line of section B-B'

(C) SECTION ALONG LINE B-B'

Old lead carbonate stope, approximate

Gray porphyry

Blue limestone

Oxidized ore

Zinc

Lead

Siliceous iron

100 0 100 200 FEET

Scale for A, B, and C

(D) ENLARGED VIEW AT BOTTOM OF INCLINED RAISE (B) SHOWING RELATION OF OXIDIZED ZINC ORE TO OTHER MATERIALS

Limestone

Porphyry

Siliceous zinc ore (20%)

Chalcodony

FLOOR OF DRIFT

0 1 2 3 4 FEET

In the Belgian mine (Fenton lease, 1913) small bodies of low-grade siliceous oxidized zinc ore were formed by the replacement of limestone at the base of a complex Gray porphyry sheet, which separated the zinc ore below from silver-lead bodies above, as shown in figure 3. Fissures containing small amounts of very low grade red

siliceous zinc material pass through the porphyry, and some of them certainly connect zinc bodies with lead-silver bodies, although the largest of the zinc ore exposures appears to have the most remote connection. There seems, however, no reason to doubt that the zinc-bearing solutions were able to travel for considerable distances through unfavorable porphyry to a more favorable place before depositing any considerable quantity of zinc.

SHAPES AND SIZES OF ORE BODIES.

GENERAL FEATURES.

The ore bodies, as shown in the different plans and sections (figs. 3 to 7 and Pls. VII and VIII), are for the most part very

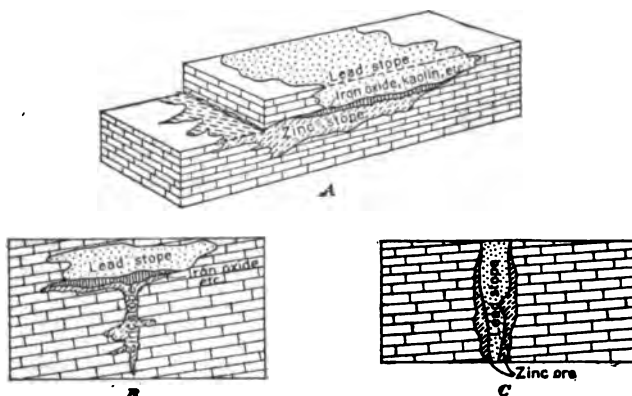


FIGURE 4.—Diagrams illustrating relations of oxidized zinc ore bodies to lead carbonate stopes in the Oro La Plata mine: *A*, Replacing beds beneath a blanket stope; *B*, replacing rock along fissure and beds beneath a blanket stope; *C*, replacing walls of a fissure stope.

irregular. Nevertheless, they show in several places structural features that go far toward indicating their origin. The simplest examples are represented in the sketches in figure 4, illustrating the mode of occurrence in the Oro La Plata mine. Figure 4, *C*, represents zinc carbonate ore of shipping grade forming borders or casings to a lead stope that had replaced the wall rock along a fissure. The zinc on oxidation of the primary (sulphide) ore evidently moved downward, at the same time permeating the limestone for a distance of 2 feet or more. Figure 4, *B*, illustrates a place where the zinc solutions, descending from a blanket sulphide body, found the easiest course along a fracture plane, replacing the fracture walls and infiltrating to some extent along the more open bedding planes. Occurrences in the Maid of Erin mine similar to these have been described by Philip Argall.¹ Figure 4, *A*, illustrates what is probably

¹ Argall, Philip, The zinc carbonate ores of Leadville: Min. Mag., vol. 10, p. 284, 1914.

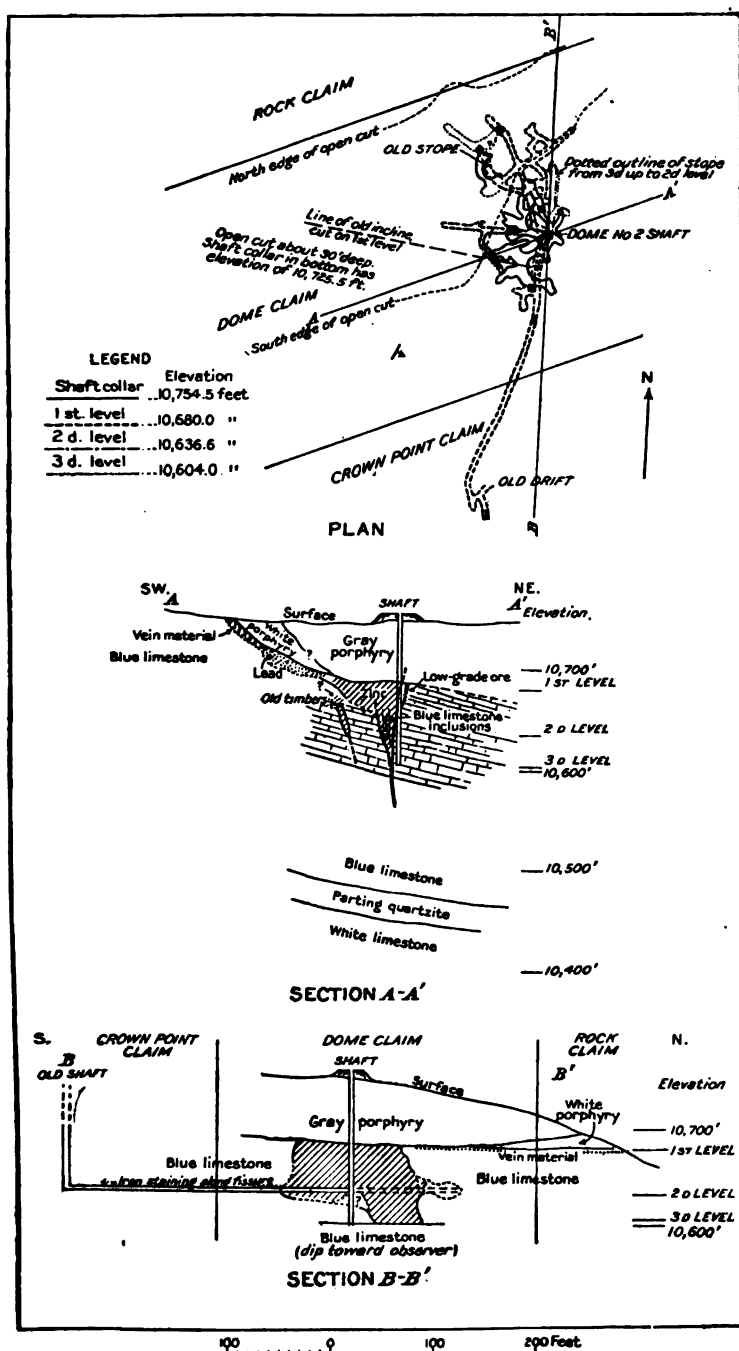


FIGURE 5.—Plan and sections showing relation of oxidized zinc ore body on the Dome claim to old lead carbonate stoep. Section A-A', an east-west section through the Dome No. 2 shaft, shows concentration of ore in shattered ground along fissures; section B-B' shows northward pitch of ore body.

the most common mode of deposition, in which the zinc solutions worked down into the beds just beneath a blanket stope and then tended to migrate downward along the dip. In one of the stopes in the Ibex mine the zinc solutions migrated outward and replaced the same strata as the original ore body, the silver-lead and the zinc stope lying side by side.

Other ore bodies represent some combination of the conditions just described. The New Dome deposit, represented by figure 5,

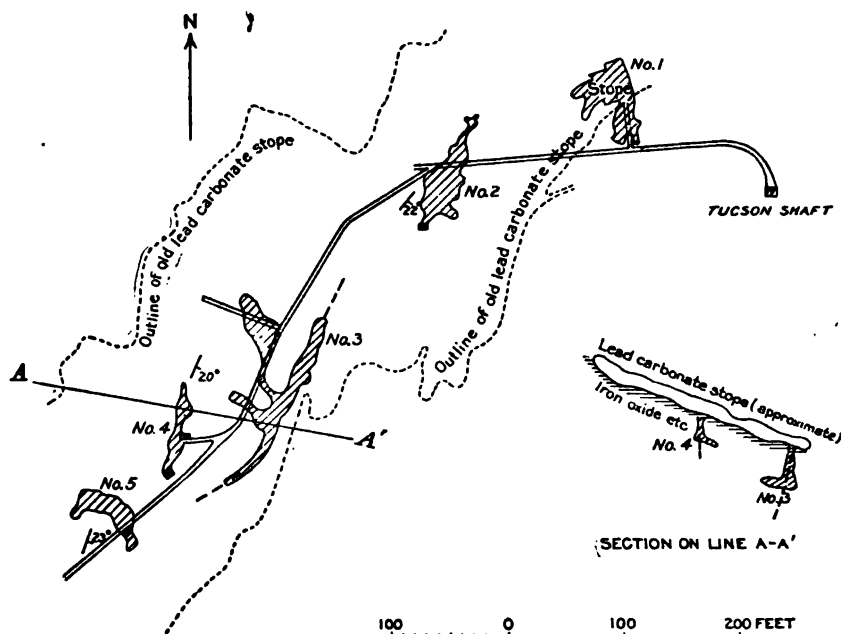


FIGURE 6.—Plan and section showing relations of oxidized zinc ore stopes (shaded) to old lead carbonate stopes, Tucson mine.

illustrates the downward migration of the zinc solutions along bedding planes just beneath a Gray porphyry sill as far as a fissured zone, which then afforded the readiest channel. The shattering of the rock along the fissure zone permitted the replacement to extend over a rather great width in proportion to length and depth.

The plan and section of the Tucson first level (fig. 6) also illustrates the development of the oxidized zinc ore bodies along fissures, with local spreading along bedding planes and minor fractures. The scattered distribution of these small bodies beneath a large continuous old silver-lead stope is in marked contrast to the extensive bodies of the northern part of Carbonate Hill.

CARBONATE HILL ORE BODIES.

The enormous size and the details of outline of the Carbonate Hill ore bodies can be explained to some extent, but the surrounding ground is so thoroughly altered and soft and in large part so inaccessible that a complete explanation of all the details is out of the question. The plan of these ore bodies is shown in Plate VII and cross sec-

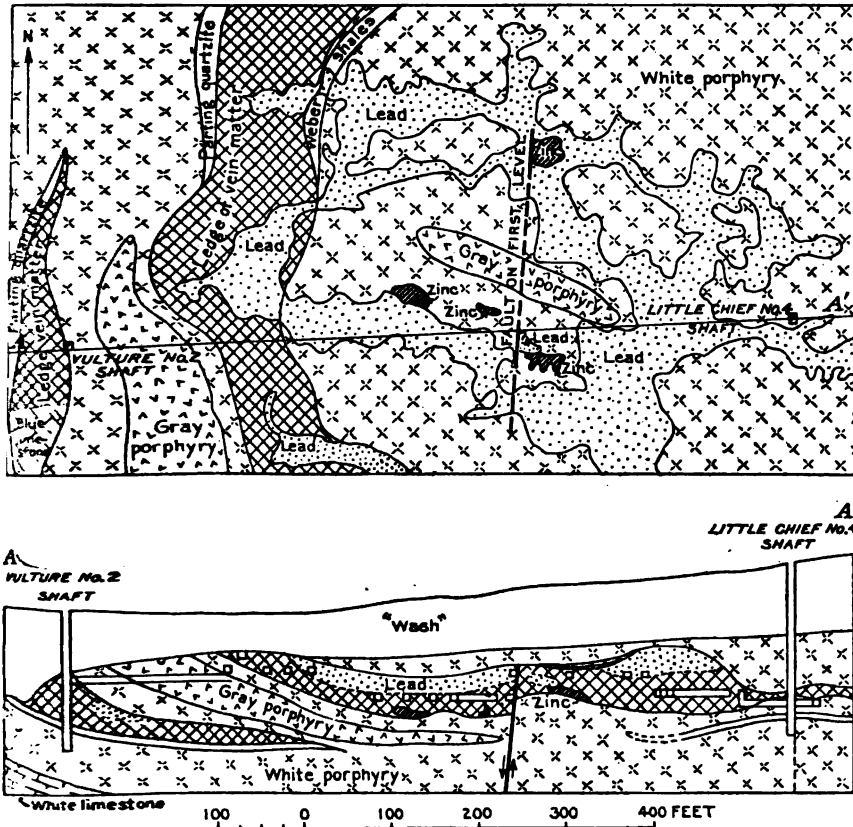


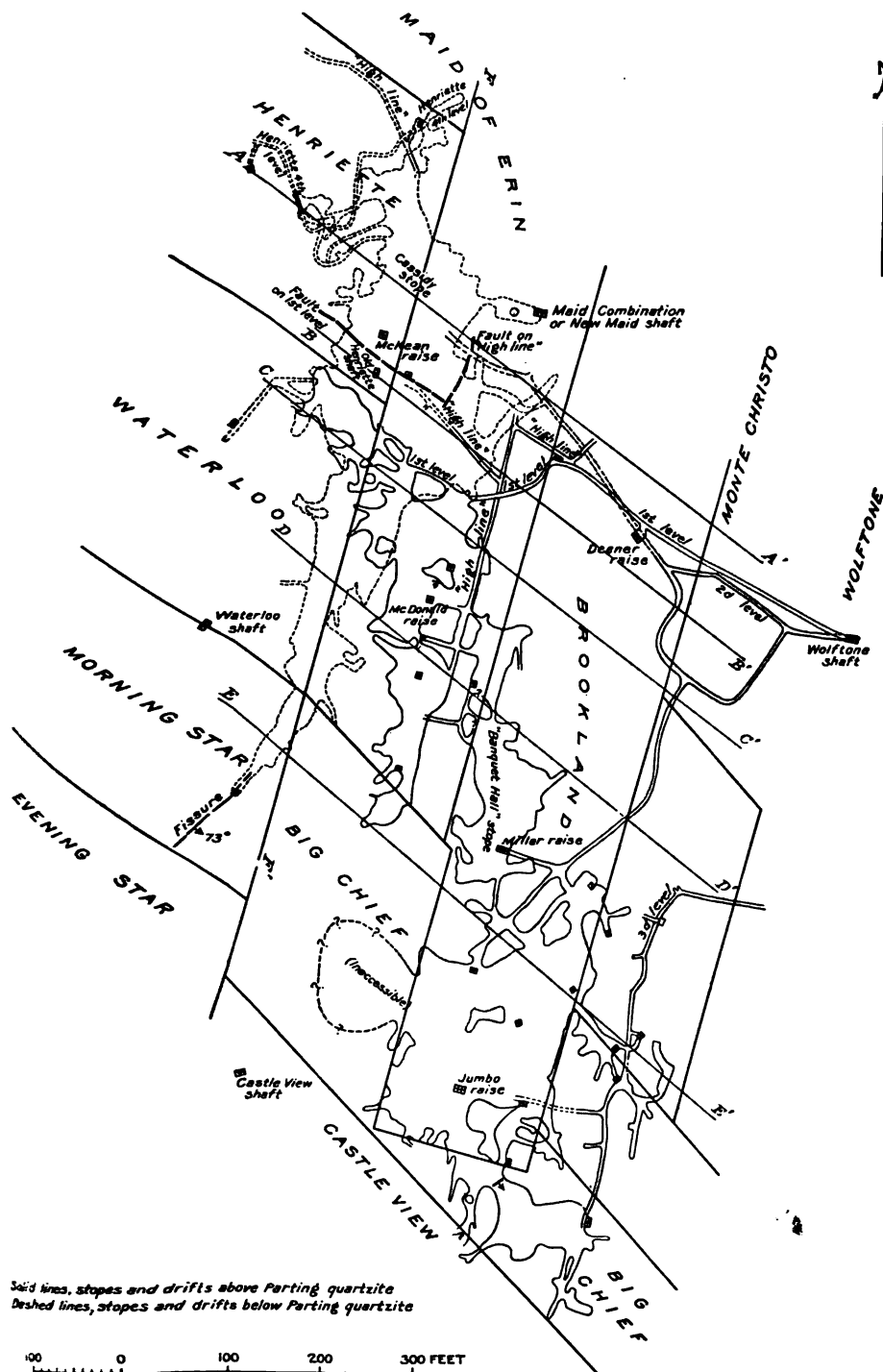
FIGURE 7.—Plan and section showing relations of oxidized zinc ore to old lead carbonate stopes in Chrysolite mine. Outlines of lead carbonate stopes copied from atlas sheet 31, U. S. Geol. Survey Mon. 12. Outlines of zinc stopes only approximate. Surface east of the outcrop of vein matter is all White porphyry except the dike of Gray porphyry in the central part of the area. Section adapted from section B-B, atlas sheet 32, U. S. Geol. Survey Mon. 12.

tions in Plate VIII. The outlines of stopes in the plan are not everywhere indications of the boundaries of the ore body. In several places the narrow stopes, which might be interpreted as branches of ore along fissures, merely represent beginnings of stopes or exploration drifts to block out ore. Other boundaries represent the limits of high-grade ore without giving any idea of the large amount

of adjacent low-grade ore (averaging near 20 per cent of zinc). The vertical sections throw more light on the dimensions of the ore bodies, but it must be remembered that the outlines of these sections are for the most part approximations, as the boundaries of the ore bodies in most places either had not been reached or were no longer accessible. The sections are somewhat generalized to include important features near but not exactly on the lines of the sections.

In sections A-A and F-F, Plate VIII, the maximum thickness, about 130 feet, of the ore body beneath the Parting quartzite is shown, the ore extending in places down to the Cambrian quartzite. Evidence pointing to the cause of this unusual thickness is very scanty but suggests a plausible explanation. Data on the size and distribution of associated old lead stopes, which have been exposed at a number of points, are scarce and indefinite. Such exposures beneath the Parting quartzite represent comparatively thin blanket bodies. A large stope has been exposed in a raise through the quartzite, but little is known of its extent and thickness. Comparison with the stope map of the monograph on the Leadville district of which this paper is to form a part will show that these old stopes lie close to the area of extreme metallization, but, although this fact indicates that there was an abundance of oxidized lead-silver ore in the immediate vicinity, there is no means of knowing whether the bulk of the zinc migrated vertically downward through the Parting quartzite, or down along the dip beneath the Parting quartzite. Both processes no doubt took place, but it can not be said which predominated.

Although the immediate sources of the zinc ore are very obscure, there is some evidence in the location of faults and open structure of the rocks to account for the great thickness of some of the ore bodies. The southeastward dip of the strata is interrupted by a fault of west-northwesterly trend (section F-F), with relative down-slip on its south side. This fault was exposed at only one place, on the first Wolftone level, and its length and exact course are not known. The amount of displacement where the fault is exposed must be at least 25 or 30 feet, according to the positions of exposures of the Parting quartzite on either side; but the Parting quartzite does not appear to have been displaced to the east, along the "high line" drifts connecting with the Deener raise, and it is therefore concluded that the fault stops against one of north-northeasterly trend, as suggested in Plate VII. A strong clay-filled fissure, corresponding in position to the suggested north-northeasterly fault, was exposed on the "high line" 90 feet east of the McKean raise. The ground on both sides of it consisted of ore or thoroughly altered carbonate rock, and no idea of the amount of displacement could be gained. It is significant, however, that ore of shipping grade was not being mined on the east side of this fissure.



This fissure with its heavy clay filling evidently served as an effective barrier, at least locally, against the spreading of the zinc solutions. The Parting quartzite, as may be inferred from sections A-A and F-F, Plate VIII, could also have served in places along both faults as a barrier against circulation along the bedding, although in the planes of both sections it happens that blocks of unreplaced carbonate rock are exposed on the up-slip sides of the fault. Just what protected these masses from replacement can only be inferred from the evidence presented in the next paragraph. The distribution of the quartzite on both sides of the fault would tend to impound the solutions and to deflect them downward to some point where they could escape from the fault block.

At several places in the stopes of this thick ore body the generally open structure of the replaced carbonate rock is well preserved, as illustrated in figure 2 (p. 42). The bedding planes are mostly open and connected by short cross fractures, thus allowing the impounded solutions to permeate the rock throughout a vertical range bounded only by the top and bottom of the White limestone. The inclusions and bordering masses of carbonate rock found here and there, including those represented in sections A-A and F-F, Plate VIII, owe their preservation, to judge from their small exposures, to the local absence of this characteristic open structure. Most of these inclusions and masses are now stained by oxidation, and no tests of their composition were made, but the inclusion represented in section A-A proved to be typical manganosiderite. A specimen of this inclusion proved to be surprisingly porous for a crystalline rock, a character which, if common to the rock as a whole, would afford more complete permeation when once the zinc solutions had gained access along the numerous bedding and fracture planes. The porosity alone, however, was evidently not sufficient to allow extensive permeation.

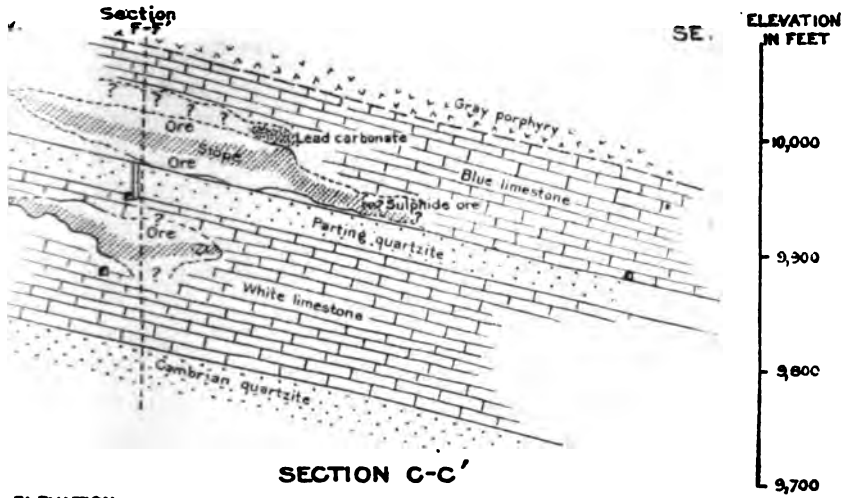
The great thickness of the ore body therefore appears to be due to a combination of three conditions—the distribution and local impounding influence of two faults, the distribution of the Parting quartzite, and the open structure of the carbonate rock in the block bounded by the faults. That the faults were not effective barriers at all points is shown in sections F-F and B-B, Plate VIII, which represent the ore body extending across the lines of faulting. So far as underground study is concerned the principal factor in determining the shape of the ore body as far south as the line of section C-C, Plate VIII, was the open structure of the rock. From this line southward the ore body gradually assumes a narrow elongate outline (sections D-D and E-E) and at its southern extremity is limited to a width of 5 feet or less, replacing the dolomite walls of a fissure. The relation of the preserved bedding planes on each side of

this fissure indicate faulting but give no idea of the amount of displacement. The occurrence in the fissure of a small amount of dense white quartz inclosing microscopic grains of a decomposed ferruginous carbonate and perhaps also of pyrite indicates a presulphide age for this fissure. The zinc ore along this fissure, as along those in other mines already described, tends to spread for short distances along the bedding and in one place was found to inclose a small bedded layer of sulphide ore, consisting chiefly of galena with cavities partly filled with calamine to mark the probable former presence of zinc blende.

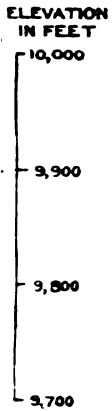
The narrow stope extending northeastward from the east side of the lower ore body between the lines of sections B-B and A-A, Plate VIII, has no apparent connection with a pronounced fissure and is not necessarily a close indication of the limits of the ore. It deserves special mention, however, because it has yielded gray zinc carbonate ore, clearly formed by the replacement of manganosiderite, directly underneath a mass of sulphides. The existence of this ore is evidently due to the migration of zinc solutions chiefly along bedding planes east of the line of the fissure described on page 59. The geology was too much obscured by timbering here to warrant a more definite statement.

The upper ore body of Carbonate Hill, above the Parting quartzite, extends obliquely down the dip from a point near the old Henriette or "Old Maid" shaft to the southwest boundary of the Big Chief claim, a distance of about 1,050 feet. Its boundaries, however, are sharply defined at only a few points, and the factors influencing its outline can only be inferred rather than determined. The branch stope that extends a little west of south, just crossing the Big Chief northeastern boundary, underlies old silver-lead stopes that have been exposed at different points. It has at one place on its west side a nearly vertical dolomite wall opposite a wall of low-grade (10 per cent) ore. No strong fissures were exposed in the ground accessible to the writer, but the trend of the higher-grade ore and the position of its walls strongly indicate replacement along a fractured zone. At one place just south of the Big Chief line the ore narrowed downward to a fissure filling only a few inches wide.

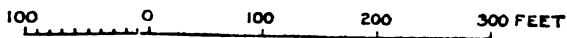
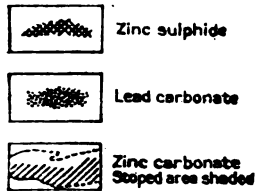
Northeast of this branch stope, about 50 feet south of the line of section C-C, Plate VIII, the zinc ore, with an inclusion of manganosiderite, was seen directly underlying a mass of pyritic sulphide ore. There was no indication of distinct fissuring in the ground accessible. The inclusion of manganosiderite, however, would, from analogy with the evidence obtained in the thick portion of the lower ore body, warrant the inference that the rock replaced by the ore was of open structure.

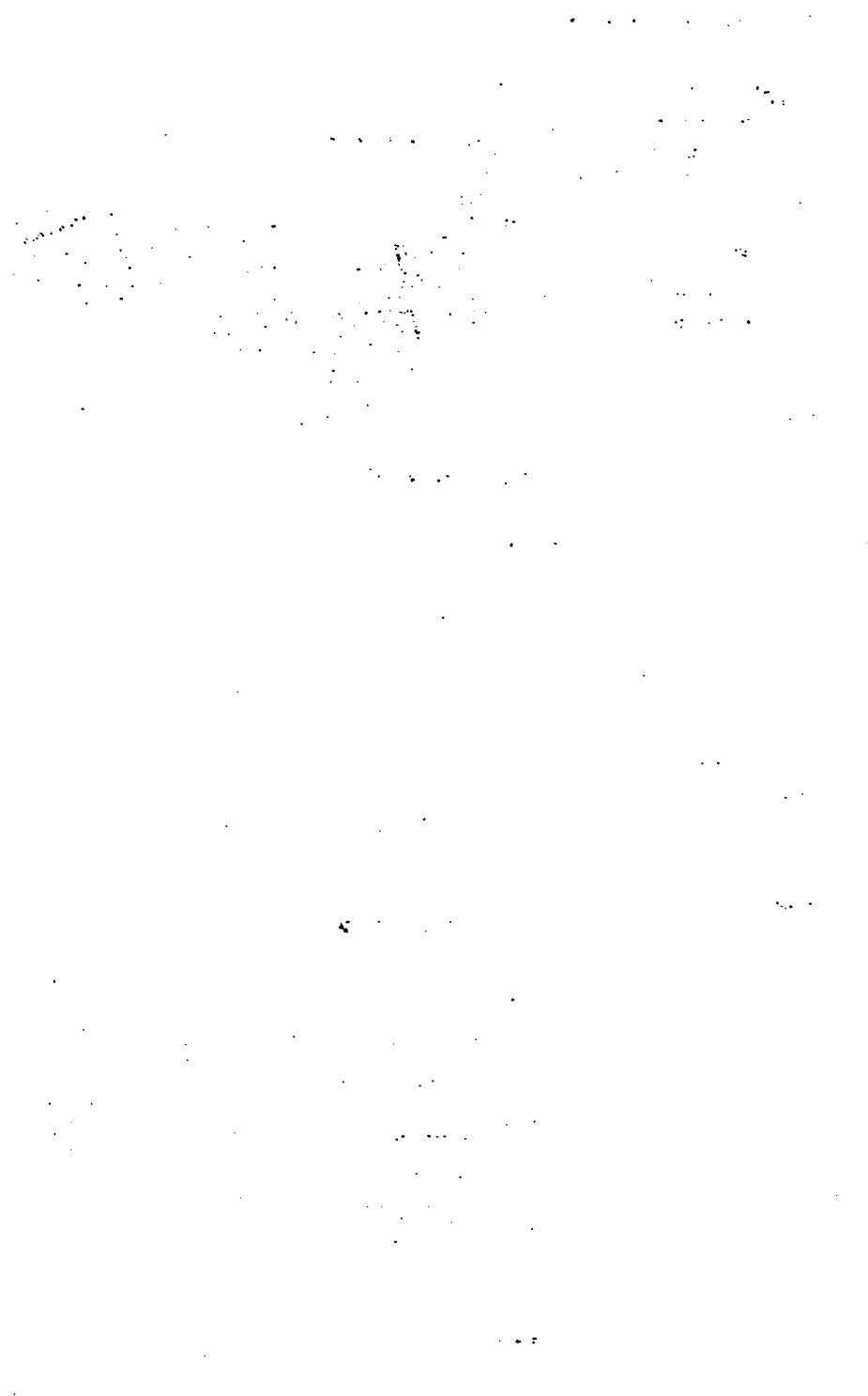


SECTION C-C'



LEGEND





About 100 feet south of this point, in the Banquet Hall stope, the ore body attained a thickness said to be 50 feet, and still farther south, a short distance beyond the line of section E-E, it was as thick or thicker. The ore was worked out in the former place, but in the latter it was seen to preserve the open structure of the original rock. This thick body underlay old silver-lead stopes, but nothing is known of their dimensions. The body diminished rapidly in thickness eastward, and on the east side of the main third level drift, along the line of section E-E, had dwindled to a bedded replacement deposit only 2 or 3 feet thick.

The most reasonable inference to account for the shape of the upper ore body, based on the scanty evidence presented, is that the rock had become more or less shattered along certain zones characterized by anastomosing fractures rather than pronounced fissures. The zinc solutions, descending from the oxidizing blanket bodies (now the old silver-lead stopes), found the easiest courses along these zones, with the result that bodies of relatively great thickness in proportion to their width were formed by replacement of the carbonate rock. The width of the ore body was limited by the extent of the openings in the rock; the depth, as shown in sections D-D and E-E, was limited by the Parting quartzite, which in places has been exposed as the approximate floor of the stopes. Whether or not these zinc solutions found their way in any considerable amount downward along fractures through the Parting quartzite has not been demonstrated by mining. It seems doubtful, however, in view of the size of the ore body and its depth with respect to oxidation, if any considerable amount of zinc carbonate or silicate ore can be expected beneath it, on the under side of the Parting quartzite.

Comparison of the position of the Carbonate Hill bodies and the slopes on the surface fails to show a concordant relation. The depths of oxidation as recorded in Emmons's notes are likewise independent of the topography, and it is evident that the depth and circulation of ground water has been governed rather by the rock structure—that is, the trends of the open portions of fissures, minor fractures, and bedding planes.

CHARACTER OF BOUNDARIES OF THE ORE BODIES.

The character of the boundaries of the ore bodies, as has already been mentioned, varies in different places, and little additional description is necessary. It seems desirable, however, to summarize the variations and to check them with certain chemical data. The simplest case includes the rather sharply defined nearly vertical walls along nearly vertical fissure bodies. The west wall of the fissure stope near the south end of the lower Carbonate Hill body is sharply

bounded by soft, sandy dolomite, a specimen of which was found by R. C. Wells to contain 1.28 per cent of zinc oxide, or 1.59 per cent of zinc carbonate. At the northwest end of the small fissure stope in the New Dome mine (fig. 5) similar but more rusted soft material bordering the stope was found by George Steiger to contain 19.22 per cent of insoluble matter, 0.36 per cent of magnesia, 0.53 per cent of lime, and 6.33 per cent of zinc oxide. The zinc here showed a stronger but still not great tendency to permeate the wall rock, which elsewhere in the mine is Blue limestone (dolomite). The insoluble material appears to be chiefly silica intimately associated with brown iron oxide and possibly combined with the zinc as zinciferous clay. This material, only a few inches thick, passed into unstained dolomite. Similar siliceous material was found along the main body of the New Dome mine on the first level. The occurrences in the Maid of Erin mine, described with assays by Argall,¹ are of similar character, though the transition from ore to country rock is more gradual.

Some of the bedded zinc carbonate bodies have rather clearly defined floors, though not nearly so sharply defined as the fissure walls just described. Two specimens taken from the floor of a small bed stope in the Ibex mine, one at the very contact of the stope and the other 5 inches below it, were found by Mr. Wells to contain respectively 27.4 and 14.9 per cent of zinc oxide, or 22 and 12 per cent of metallic zinc. These figures indicate a gradual change from ore into country rock within a zone between 1 and 2 feet thick. The bottom of the upper ore body of Carbonate Hill is in places abruptly bounded by the Parting quartzite, the top layers of which have been deeply stained by iron and manganese oxides, which may be accompanied by a little zinciferous clay. The lower ore body is said to be similarly floored by the Cambrian quartzite at a few places. At one place in the lower ore body, about 230 feet west-northwest of the Deener raise (Pl. VII), the high-grade ore passes downward into a decomposed low-grade material consisting chiefly of silica with minor amounts of iron oxide and clay, which appears to be the residue of a siliceous or silicified carbonate rock. In other places the ore passes downward into unaltered carbonate rock. Such variations evidently depend on the composition of the rock replaced and on the amount of leaching that has been possible since the deposition of the zinc ore.

The sides of the bedded bodies may be rather abruptly bounded, but much more commonly they are marked by a gradual decrease in zinc content so that the high-grade ores merge into large bodies of ore averaging near 20 per cent in zinc. How extensive such low-grade bodies are has not been definitely stated, but they are said to constitute large reserves in several different places.

¹ Argall, Phillip, *The zinc carbonate ores of Leadville: Min. Mag.* (London), vol. 10, p. 284, 1914.

The main factor determining the character of the boundary is evidently rock structure. Where permeable rock is abruptly limited, as along clear-cut fissures or impervious beds, either of quartzite, shale, or porphyry, the contact is also abrupt; where the rock bordering the main ore channels is of more open structure, there is likely to be a gradation from high-grade ore through a large extent of low-grade ore into barren rock. In the latter case the degree to which zinc is concentrated in the solution may be an important factor, solutions above a certain strength readily replacing the rock, whereas solutions below that strength but otherwise under similar conditions could react only slowly and to a small extent. No experimental data are at present available to throw light on this matter.

The upper contacts of the ore bodies are marked for the most part by layers of siliceous iron oxide and clay in varying amounts, which separate the zinc ore from overlying lead-silver bodies. These layers range in thickness from a few inches to 6 feet or more. They are characteristic of oxidized zinc deposits in several mining districts and are subject to more than one interpretation. They may represent the first substances deposited by the solutions that transferred material downward from the oxidizing sulphide bodies; they may represent the oxidized residue of a largely insoluble material which formed a casing to the original sulphide bodies; they may be the insoluble residue left by the leaching of the topmost part of the zinc carbonate body; or they may consist principally of material leached from the original ore bodies at a relatively late stage and deposited at the same time that the topmost part of the zinc carbonate was being leached. Partial evidence in different places suggests one or another of these processes, and it is possible that a combination of processes took place. It is also possible that one process may have been of relatively great influence in one district and of relatively slight influence in another, owing to differences in chemical conditions. The chemical conditions are considered in the discussion of ore genesis (pp. 68-85).

Where the oxidized zinc bodies have been seen immediately underlying porphyry or shale, their upper contacts are marked by a layer of zinciferous clay that may be 2 or 3 feet in thickness. The presence of the clay is evidently due to the alumina and silica leached from or residual after the porphyry or shale. In some places it seems that the alumina must have been precipitated with the zinc; in others it seems probable that the clay, already present, has adsorbed zinc from solutions which have come into contact with it.

At a few places bodies of oxidized zinc ore have been found in contact with bodies of iron or manganiferous iron ore. These contacts are considered in the following paragraph.

RELATIONS TO OXIDIZED IRON AND MANGANIFEROUS IRON ORES.

The oxidized zinc ores have been found beside and beneath oxidized iron and manganiferous iron ores and have also been reported to occur above them. The evidence obtained by the writer, while affording some explanation of these variations in distribution and occurrence, does not point to any systematic association. The lack of systematic association may be appreciated when it is realized that the iron ores may have originated from the complete oxidation of either pyrite or manganosiderite masses, and that the zinc ore may have been deposited directly either beneath or beside masses of either of these materials; also that the primary shoots of zinc blende from which the oxidized zinc ores were derived were irregularly scattered through the sulphide bodies or were in places underlain by manganosiderite. The evidence as a whole indicates that if either an oxidized iron or zinc ore body is present a body of the other may be present close by; but the relative position of the two bodies can not be predicted. In view of the relative abundance and distribution of the primary minerals, pyrite, manganosiderite, and zinc blende, it is evident that the presence of the iron ore is not a certain indication of the presence of the zinc ore, for large bodies of almost pure pyrite bordered by manganosiderite are known to exist with no noteworthy amount of zinc blende in the immediate vicinity. Oxidation of such a body would yield a large deposit of iron and manganiferous iron ore, with no associated body of zinc ore.

VERTICAL DISTRIBUTION AND RELATION TO DEPTHS OF OXIDATION AND GROUND-WATER LEVEL.

Oxidized zinc ores have been found in a few places close to and even at the surface and at varying depths down to 750 feet. The depths at different places depend as a rule on the depths of the contact of the White porphyry and Blue limestone, as most of the zinc bodies have been found in association with the "first contact" ore bodies of this horizon. The deepest deposit in the northern part of the Maid of Erin mine is associated with a series of ore bodies including "second contact" bodies (below Gray porphyry) and with bodies just above and just below the Parting quartzite. It is in the White limestone, extending in places from the base of the Parting quartzite even down to the top of the Cambrian quartzite. This is the thickest and one of the largest two oxidized zinc ore bodies thus far worked in the Leadville district. It is associated with the thickest as well as one of the most continuous bodies, or series of bodies, of lead-silver ore in the district, and general conditions

appear to have been favorable to concentration rather than dispersion of the zinc.

All the zinc carbonate and silicate thus far mined have been found in the zone of complete oxidation, except the lowest parts of the great Carbonate Hill bodies. These, as indicated in sections A-A to F-F, Plate VIII, in places underlie sulphide ore. In some of these places the zinc ore is practically in immediate contact with the sulphides and may even inclose small amounts of them and of associated manganosiderite. Here the zinc ore has been deposited below the local depths of oxidation.

These exposures of sulphides over or within the zinc ore have been made at depths of about 640 to 700 feet and more below the collar of the Wolftone shaft. Old lead carbonate stopes were noted as far down as about 650 to 660 feet below the shaft collar. These figures, based on observations at several places in the Western Mining Co.'s ground, place the average local depth of complete oxidation about 640 to 650 feet below the collar of the Wolftone shaft, or at an elevation of about 9,950 feet. They correspond closely with figures in Emmons's notes, for he found the depths of oxidation to be at an elevation of 9,936 feet (660 feet below the surface) in the Wolftone mine, 9,941 feet (639 feet below the surface) in the Brookland, and 9,981 feet (667 feet below the surface) in the Upper Henriette. Emmons's notes, however, show that the depth of oxidation fluctuates considerably in the northern part of Carbonate Hill.

The relation of the oxidized zinc ores to ground-water level can not be definitely shown, because the original water levels in different places have been greatly disturbed by underground operations. All the ore bodies studied, except those in the northern part of Carbonate Hill, are well above the original ground-water level, so far as can be learned from available data. It is stated that in northern Carbonate Hill water to-day would rise to a level about 300 feet below the surface in the Wolftone shaft were pumping operations to cease. This is over 300 feet above the average depth of complete oxidation and well above all the oxidized zinc bodies thus far mined. It can not, therefore, be considered as any indication of the original ground-water level. Neither can the average depth of complete oxidation be considered a close indication of the original ground-water level, as oxidation is known to extend somewhat below that level in some places and considerably below it in excessively fractured zones. On the other hand, sulphide bodies of small to considerable size are found, in more protected ground, above ground-water level. The depths at which the zinc carbonate and silicate are found are also unreliable indications, for the reason that they

may be deposited by the replacement of limestone below as well as above ground-water level. The composition of the zinc carbonate ores is such as to indicate that they were deposited in the absence of free oxygen, a condition that may exist in the lower part of the ground above the water level as well as below it.

The zinc carbonate ores also show that they themselves have certainly, to a large extent, undergone considerable oxidation and leaching, a fact which proves the downward migration of the oxidized zone since the bulk of the carbonate ores were deposited. The ground-water level also doubtless migrated downward, keeping pace with surface erosion. It is obvious, therefore, that no exact relations can be determined between the distribution of the oxidized zinc ores and the ground-water level. The evidence as a whole, however, indicates that the zinc carbonate ores were deposited close to if not in part below the water level that then existed, and it is possible that their lower portions were still below the natural water level that existed just prior to the disturbances caused by mining.

LACK OF ASSOCIATION WITH SECONDARY SULPHIDES.

No evidence of secondary sulphides of any kind was found in connection with the oxidized zinc ores, and no positive evidence of secondary zinc sulphide was noted anywhere in the district. The sulphide ore exposed in contact with the zinc carbonate ores had all the characteristics of primary ore. Even small grains of pyrite, zinc blende, and galena found inclosed in the ore proved under the microscope to be intimately associated with veinlets and patches of quartz and sericite, the typical gangue minerals of primary sulphide ore. The three sulphides, as well as the quartz and sericite, were evidently unaffected by the zinc-bearing solutions that replaced the carbonate rock.

The sulphide masses adjacent to the zinc carbonate ore are all composed largely, if not entirely, of pyrite, but no sign of zinc sulphide, either sphalerite or wurtzite, upon pyrite was found. This is a point of some significance in view of the conclusions expressed by Blow and Emmons (see p. 10) that the zinc removed from the oxidized zone had been precipitated just below water level and had thus migrated downward at equal pace with the limits of oxidation. The only available agents for the precipitation of zinc as a sulphide, on the assumption that the zinc was in solution as sulphate, were a very small quantity of organic matter and a large quantity of pyrite.

It has been assumed by some writers that pyrite or marcasite has precipitated secondary zinc sulphide, especially in deposits of the

Mississippi Valley; but experiments with the two minerals have not confirmed this assumption, at least in a convincing way. The experiments of Schuermann¹ and Weigel² lead to the conclusions that under certain conditions zinc has a slightly stronger affinity for sulphur than iron has—in other words, that zinc sulphide is slightly more insoluble than iron sulphide—but that the two metals are so very nearly equal in solubility that any precipitation of zinc sulphide at the expense of an iron sulphide would not be nearly so marked as a precipitation of silver or copper sulphide by the same agent. The conditions of these experiments by no means duplicate the conditions governing the secondary deposition of zinc minerals at Leadville. So far as they go, they may suggest that if pyrite can precipitate zinc sulphide from the ground waters in question, it does so very slowly and can hardly precipitate large quantities of zinc blende just below the zone of oxidation.

The only experiment, to the writer's knowledge, in which zinc sulphide has been precipitated by pyrite or marcasite is one by Stokes³ who treated pyrite and marcasite each with an excess of zinc carbonate and potassium bicarbonate in sealed tubes filled with carbon dioxide for 24 hours at 180° C. Other experiments under similar conditions, also by Stokes, on the action of alkaline solutions alone on pyrite and marcasite show that the alkaline solutions, including potassium bicarbonate, decompose pyrite and marcasite. It therefore seems probable that the potassium bicarbonate was the influential factor in making the precipitation of zinc sulphide possible. In the Leadville deposits the secondary zinc solutions, whether sulphates or carbonates, evidently found the surrounding carbonate rock to be more readily replaceable than the pyrite. After the zinc carbonate had been thus precipitated the conditions, including low temperature as well perhaps as absence of a sufficient amount of alkali in solution, were not right to convert it to secondary sulphide at the expense of pyrite.

Experimental evidence is thus negative, and local field evidence shows that conditions were not favorable for the precipitation of secondary zinc sulphide. Local evidence furthermore accords with general evidence, which has been discussed by W. H. Emmons,⁴ who says:

It has frequently been stated that zinc sulphide has been precipitated at the expense of iron sulphide and that zinc has driven iron out of its sulphide com-

¹ Schuermann, Ernest, Ueber die Verwandtschaft der Schwermetalle zum Schwefel: *Lebig's Annalen*, vol. 249, p. 326, 1888.

² Weigel, Oskar, Die Löslichkeit von Schwermetallsulphide im reinem Wasser: *Zeitschr. physikal. Chemie*, vol. 58, pp. 293–300, 1907.

³ Stokes, H. N., Experiments on the action of various solutions on pyrite and marcasite: *Econ. Geology*, vol. 2, p. 17, 1907.

⁴ Emmons, W. H., The enrichment of sulphide ores; *U. S. Geol. Survey Bull.* 529, p. 86, 1913.

bination, but no examples of the pseudomorphous replacement of pyrite or marcasite by zinc blende are available. On the other hand, Hintze¹ notes a pseudomorph of marcasite after zinc blende.

Lindgren² states that "zinc is not, as a rule, deposited as a secondary sulphide, and no authentic case has been recorded where it replaces pyrite, as chalcocite so often does." In his discussion of Bain's conclusion that secondary zinc and other sulphides have been deposited at Joplin, Mo., below the zone of oxidation, he states³ that "possibly this has taken place on a small scale, but most of the ore immediately below the oxidized zone appears to be of primary origin."

In a few places, the most recently discovered of which has been described by B. S. Butler,⁴ wurtzite, the hexagonal form of zinc sulphide, occurs as a probable secondary mineral. Butler, while suggesting that the replacement of pyrite by zinc sulphide may be possible, remarks that—

in none of the ore examined can the zinc sulphide be seen replacing the iron, but there are abundant specimens that show wurtzite surrounding sphalerite, apparently as a later growth on it. This suggests that the precipitation has been effected by agents other than the pyrite, and that the attraction of the sphalerite had caused the secondary sulphide to be added to it. * * * E. T. Allen and J. L. Crenshaw have suggested that acid solutions containing zinc sulphate and hydrogen sulphide in solution on having their acidity reduced would precipitate zinc sulphide. That such solutions are formed in the zone of oxidation there can be little doubt, and as they pass to lower levels their acidity may be reduced either by solutions from the adjacent limestone or by reaction with alkali silicates that form a part of the gangue of the ore.

From this evidence it would seem possible that wurtzite could be found crystallized upon zinc blende in some of the Leadville deposits at or below the downward limit of oxidation, but no such occurrence, to the writer's knowledge, has been reported. So far as positive evidence is concerned, no bodies of secondary zinc sulphide have been formed. The bodies of zinc blende just below the zone of oxidation, referred to by Blow and Emmons, can doubtless be interpreted as primary and can be shown to differ in no essential way from other segregated deposits of zinc blende found well below the zone of oxidation, such as have been found in the Cord mine below the level of the Yak tunnel.

GENESIS.

That the oxidized zinc ores of the Leadville district are believed to have been derived through oxidation of zinc blende in the original

¹ Hintze, Carl, *Handbuch der Mineralogie*, vol. 1, p. 481.

² Lindgren, Waldemar, *Mineral deposits*, p. 811, 1913.

³ *Idem*, p. 834.

⁴ Butler, B. S., *Geology and ore deposits of the San Francisco and adjacent districts, Utah*: U. S. Geol. Survey Prof. Paper 80, p. 154, 1913.

sulphide ore must be apparent to all who have read the foregoing pages. Below are considered the chemical processes involved in the derivation. Some of the evidence afforded by study of the specimens and underground workings may not accord perfectly with all the experimental data available, and such discordances necessarily leave some doubt as to the exact conditions of chemical equilibrium which existed and which exerted a greater or less influence on the reactions that took place. The genesis of the ores may be conveniently considered in three stages.

FIRST STAGE.

DERIVATION OF MATERIALS.

The original ore bodies consisted essentially of the ore minerals pyrite, zinc blende, and galena, with small amounts of chalcopyrite in places and of the gangue minerals manganosiderite, quartz, and sericite, the gangue minerals for the most part forming a casing around the ore bodies. The zinc blende was the ferruginous variety, marmatite, composed of about 3 parts zinc sulphide and 1 part iron sulphide, as shown by the following analyses:

Analyses of zinc ore from Leadville district.^a

[A. W. Warwick, analyst.]

	Adams	Colonel Sellers.	Yak.
Zinc ^b	52.8	47.6	45.1
Sulphur	34.7	35.7	36.4
Iron ^c	12.1	14.8	17.8
Silica .....	.2	.4	.2
	99.8	98.5	99.5

^a Bein, H. F., U. S. Geol. Survey Mineral Resources, 1905, p. 384, 1906.

^b Includes cadmium, which varied from 0.1 to 0.35 per cent.

^c Includes manganese, which varied from 1.3 to 3.7 per cent.

Study of the sulphide ores in the Leadville district and of similar ores in other districts shows that the zinc blende is the first of the ore minerals to be removed by oxidation and may be nearly or quite all removed before the other sulphides are attacked to any considerable extent. The rapidity and thoroughness of removal would obviously depend on the degree to which oxidizing solutions could permeate the ore of the three sulphides. Galena is the most protected from oxidation, owing to the insolubility of the sulphate which forms around it. The writer has seen very little chalcopyrite in place at Leadville and has no definite data at hand regarding its position in the order of oxidation. His observations of ores in other districts would lead him to favor the view that chalcopyrite

underwent oxidation before the pyrite and after the zinc blende—a view which accords with the occurrence of copper in the oxidized zinc ores at Leadville and with the interpretation of their genesis but which does not harmonize with certain experimental data.¹ The conditions of these experiments, however, do not approach very closely the natural conditions under which the Leadville ores were oxidized.

These experimental data have been summarized and discussed by W. H. Emmons, who makes the following concluding statement: "All these experiments and observations seem to indicate that in the zone of oxidation in many deposits the sulphides are dissolved in the following order: Sphalerite (?), chalcocite, pyrrhotite, chalcopyrite, pyrite, galena, enargite." The positions of sphalerite, chalcopyrite, pyrite, and galena in this order accord with the writer's observations.

The ore bodies are covered by a greater or less thickness of porphyry, through which the oxidizing waters must have descended. Those bodies which are exposed at the present surface were once covered by porphyry, or in some places by the Parting quartzite and porphyry, and oxidation in all probability began before these overlying rocks were removed. Possible exceptions may have existed locally where sulphide bodies unusually well protected from preglacial oxidation were exposed by glacial scouring and were later oxidized by waters that had not previously passed through porphyry; but study of the geologic sections in the atlas accompanying Monograph 12 shows convincingly that in practically all the places where oxidized zinc ore bodies have been found the oxidizing waters must have descended for considerable distances along major and minor fractures through porphyry.

The porphyries which the writer has studied, both White and Gray, are extensively altered to aggregates of pyrite, quartz, and sericite, and it is most probable that alteration of this type extended for a considerable distance above the "first contact" bodies. The descending waters, therefore, already containing oxygen and carbon dioxide from the air, attacked and decomposed the pyrite, taking ferric and ferrous sulphates and sulphuric acid into solution. In the earliest stages of oxidation the supplies of oxygen as well as of free sulphuric acid and ferric sulphate may have become exhausted through further reactions before reaching the ore bodies, but as the erosion surface and the limits of complete oxidation were gradually lowered these active reagents persisted until the ore bodies were reached. The waters at this stage probably contained in solution considerable quantities of alkalis, alkaline earths, carbon dioxide, and oxygen, but larger quantities of the two iron sulphates and sulphuric acid.

¹ Emmons, W. H., The enrichment of sulphide ores: U. S. Geol. Survey Bull., 529, pp. 76-78, 1912.

The presence of alkalis and alkaline earths may have exerted some influence in accelerating the processes of solution and deposition, as suggested by Nishihara.¹ Minor quantities of alumina and silica also were doubtless present in solution, as indicated by the composition of many mine waters that have percolated through pyritized siliceous rocks.²

Of these constituents sulphuric acid, ferric sulphate, and oxygen had the most influence on oxidation and the removal of the sulphides. It is doubtful if carbon dioxide could have exerted much solvent action on zinc blende, so long as these three constituents were present in excess, owing to the much higher degree of solubility of zinc sulphate than that of zinc carbonate. This statement is supported by the fact that where descending waters have locally evaporated in the Leadville mines, deposits of goslarite, the zinc sulphate, have been found, but none of a zinc carbonate. Experiments by Gottschalk and Buehler³ have shown that although zinc blende alone when leached by water is oxidized very slowly, the process is hastened if the water has first descended through pyrite or marcasite—that is, if it has first become charged with sulphuric acid and ferric sulphate. They have shown also that oxidation is much more rapid if the blende is in contact with galena or especially with pyrite, the oxidation being accelerated by electrolytic action. The water used in these experiments is not strictly analogous in composition to the ground waters that had descended through the pyritized porphyries of Leadville, but the results of the experiments accord with those of the natural process. Whatever the exact reactions were, the zinc blende was oxidized before the other two sulphides, and there is little doubt that the zinc and iron of the zinc blende were removed as sulphate.

The supply of free oxygen in these solutions probably became exhausted at an early stage of the process, and it may be that more or less sulphuric acid and ferric sulphate were still available for further reactions. Experiments by R. C. Wells⁴ have shown that sulphuric acid, out of contact with air, dissolves zinc blende more readily than it dissolves either galena, pyrite, or chalcopyrite, converting the zinc to sulphate and setting free hydrogen sulphide. The hydrogen sulphide, if free to escape upward, could finally reach the zone of free oxygen, oxidize, and thus tend to renew the supply of sulphuric acid; if not free to escape it could, after the sulphuric acid had become exhausted, possibly succeed in reprecipitating some of the zinc as the hexagonal sulphide, wurtzite, but no evidence has been found to

¹ Nishihara, G. S., *Geology and ore deposits of the Tetlixe district, Russia*: Econ. Geology, vol. 12, pp. 277–278, 1917.

² Analyses of 27 such waters are tabulated and discussed by W. H. Emmons (U. S. Geol. Survey Bull. 529, pp. 60–74, 1913).

³ Gottschalk, V. H., and Buehler, H. A., *Oxidation of sulphides*: Econ. Geology, vol. 5, pp. 28–36, 1910; vol. 7, pp. 15–34, 1912.

⁴ Emmons, W. H., *op. cit.*, pp. 59, 76.

show that this reaction has taken place in the Leadville deposits. Ferric sulphate, out of contact with air, could also convert the zinc and iron in zinc blende to sulphates, setting free sulphur and itself changing to ferrous sulphate. The disposition of the free sulphur under these conditions is questionable, but there is nothing to indicate that it played a conspicuous part in the genesis of the oxidized zinc ores. The results of these reactions which may have taken place after the free oxygen in the descending waters had become exhausted served to supplement those of the reactions which had taken place before—in other words, to increase the amount of zinc sulphate, and also of ferrous sulphate, already in solution.

After the reactions that produced zinc and iron sulphates in solution had been completed, the carbon dioxide in solution may have aided to a minor extent in the further decomposition of zinc blende by uniting with some of the zinc in solution as bicarbonate, leaving a corresponding amount of sulphuric acid to continue attack on the sulphide. The original amount of carbon dioxide in solution may have been considerably increased if the descending waters passed through any carbonate rock, either manganosiderite or dolomite, before their supplies of sulphuric acid and ferric sulphate had become exhausted.

The reactions outlined above are believed to include all that appear to have been important in the decomposition of zinc blende and the provision of a supply of zinc available for deposition as oxidized ore. The materials that were taken into solution, or left in solution, as a result of such reactions are principally zinc sulphate, ferrous sulphate, and more or less zinc and iron carbonate, with corresponding amounts of lime, magnesia, and manganese sulphate.

DEPOSITION OF MATERIALS FROM SOLUTION.

Deposition in the oxidized zone may take place by processes of hydration and oxidation of the solutions, desiccation or evaporation, reaction or metasomatic interchange with the wall rock, and reaction between different solutions. The first two of these processes have resulted in deposition of some iron sulphate, goslarite (the hydrous zinc sulphate), hetaerolite, hydrozincite, some smithsonite, and calamine. Reaction between different solutions may have caused deposition of some of the zinciferous clays, waters descending through porphyry with alumina and silica in solution reacting with zinc-bearing waters that percolated along the lower contact of the porphyry and depositing the layers of zinciferous clay along the bottom of the porphyry. Metasomatic interchange with the wall rock, however, has been the chief agent in producing the deposits of commercial grade, although these deposits have been more or less reworked by one or more of the other processes.

The disposition of the materials can most conveniently be discussed by following the different courses which the water may have followed after its leaching of the zinc from the sulphide bodies. Where the water, after taking zinc sulphate into solution, became locally supersaturated through desiccation, while still in the sulphide body or in a porphyry sill beneath the sulphide body, goslarite was formed (and is being formed), lining fractures and other openings. The only occurrence of goslarite seen by the writer in his study of the Leadville sulphide ores was a coating on pyritic sulphide ore along a drift on the sixth level of the Tucson mine. The mineral here formed white, soft, fine, hairlike crystals associated with relatively thick prisms of epsomite, a hydrated sulphate of magnesia, the two minerals forming a parallel fibrous growth. Such deposits are only temporary, being redissolved sooner or later by unsaturated waters which reach them.

Where the waters pass through the sulphide bodies into underlying rocks two sets of conditions may be considered, according to the kind of rock (porphyry or carbonate rock). Each of these sets of conditions may be subdivided into two phases—one in which the free sulphuric acid and ferric sulphate have not been exhausted and the other in which they have been exhausted. If the underlying rock is sericitized porphyry, and sulphuric acid and ferric sulphate are present, either or both of these reagents will tend to decompose the sericite and any unaltered feldspar in the porphyry, taking into solution silica and sulphates of alumina and alkalies. The alumina and silica will tend to be precipitated again, perhaps without having traveled for any considerable distance, as kaolin, or material of similar composition and appearance. This process will also cause the deposition of an indefinite amount of zinc and result in zinciferous clay. Whether the zinc is deposited simultaneously with the other materials as a primary constituent of the clay or through the replacement of aluminum in clay previously deposited is an open question. Where the percentage of zinc in such clay is very high it could be regarded as a primary constituent; where the percentage of zinc is low it could be regarded either as the result of replacement or as a primary constituent of clay deposited from a solution poor in zinc. The origin of the iron and manganese oxides locally present in these clays is obscured by their segregation, since their deposition, into red, brown, and black patches and streaks. They, like the zinc, may have been original or secondary (adsorbed) constituents of the clay. Under all these suppositions the precipitation of aluminum and zinc compounds from solution may imply the liberation of a corresponding amount of sulphate radicle and the renewal of sulphuric acid capable of dissolving new portions of the rock and tending to

repeat the process until the water itself should become exhausted or should reach ground-water level.

Where the entire process has taken place within the porphyry mass, the zinciferous clays are scattered along fissures and minor fractures in the porphyry; where the waters containing the constituents of the clay in solution passed through the porphyry into carbonate rock, the clay was deposited through metasomatic replacement, the size and shape of the deposit depending on the relative openness of fractures and bedding planes and on the amount of clay material introduced. The chemical reactions involved in this replacement are not simple, but the replacement of carbonate rocks by masses of kaolin is not an uncommon occurrence.

It is believed that the process outlined above goes far toward explaining the occurrence of low-grade siliceous and argillaceous zinc ore like that at the base of a porphyry sill in the Belgian mine. (See fig. 4, p. 54.) This ore contains veinlets and vugs lined or filled with calamine, which was deposited with and just after the clay and appears to represent the excess of zinc over that which could be contained by the clay. The opal and chalcedony closely associated with the calamine represent a further excess of silica. The presence of calamine appears also to indicate that sulphuric acid and ferric sulphate had become exhausted, and that zinc sulphate in the neutralized solution, concentrated by depletion of the water, could not remain in solution in the presence of an excess of silica. The absence of any conspicuous amount of smithsonite in this deposit is noteworthy as an indication that carbon dioxide was a very minor constituent of the solution which introduced the zinc. The presence of a few microscopic needles of aurichalcite associated with the calamine and chalcedony also points to the scarcity of carbon dioxide, as it is probable that the basic carbonates of zinc are deposited when there is no excess of carbon dioxide.

It is known that sodium carbonate produces a basic carbonate of zinc, when added to zinc sulphate; on the other hand, sodium bicarbonate yields a normal carbonate. Raikow¹ showed that an excess of carbon dioxide transforms the hydroxide of zinc into the normal carbonate.

If the descending waters on passing from the sulphide body into underlying porphyry have been depleted of their free sulphuric acid and ferric sulphate, it is doubtful if any considerable replacement of the wall rock can occur, at least until the waters become concentrated through depletion or adsorption by wall rock material. It seems unlikely that the difficultly soluble minerals of the porphyry can be readily replaced by interchange with the easily soluble sul-

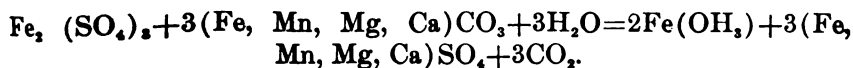
¹ Raikow, P. N., *Weitere Untersuchungen über die Einwirkung der Kohlensäure auf die Hydrate der Metalle*: Chem. Zeitung, vol. 31, p. 55, 1907.

phate of zinc, and no indication of such a process has been noted. It seems probable, on the other hand, that such a solution will pass through the porphyry until ground-water level is reached, or until concentration by the above-mentioned factors causes the deposition of goslarite, or of calamine in the presence of sufficient silica, or of zinciferous clay in the presence of alumina and silica. The alumina and silica would presumably have been derived chiefly from gangue material within the sulphide body and from porphyry above the ore body. Workable deposits of calamine with more or less zinciferous clay could be formed in this way where excessive fracturing of the porphyry would afford an opportunity. It is possible also that in such places some replacement of the shattered porphyry by these minerals could be effected if the solutions were sufficiently concentrated, but no such deposits in porphyry have been noted at Leadville.

If the solution with a high content of zinc should pass through the porphyry into carbonate rock, deposition of the zinc as carbonate by replacement would be possible, and the process would be analogous to that described below.

None of the Leadville deposits can be attributed chiefly to this set of conditions, although the occurrence of zinc carbonate bodies separated from parent sulphide bodies by a sheet of porphyry is a possibility. If the solution were low in zinc and in consequence relatively high in silica and alumina, calamine and zinciferous clay could be expected, as the conditions would be similar to those illustrated by the occurrence in the Belgian mine.

Where the solution passed directly from the sulphide body into carbonate rock, either manganosiderite or dolomite, and contained an excess of sulphuric acid and ferric sulphate, the sulphuric acid would at once be neutralized by reaction with the carbonates. If free oxygen were also present in solution, a corresponding amount of ferrous sulphate formed by the reaction would be oxidized to ferric sulphate, and this together with ferric sulphate already in solution would react further with the carbonate rock and be precipitated as ferric hydrate, according to the following equation:¹



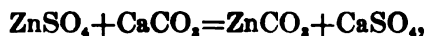
The ferric hydrate thus formed would, by gradual loss of a part of its water, be gradually transformed into one of the hydrous oxides and thus account for a part of the iron oxide in the layers that separate the lead-silver stopes above from the zinc carbonate stopes

¹The action of sulphuric acid and ferric sulphate on limestone has been studied by W. Meigen (*Beiträge zur Kenntnis des Kohlensauren Kalkes: Naturforsch. Gesell. Freiburg im Breisgau Ber.*, vol., 13, p. 76, 1903). The equation given above is adapted from one given by Meigen, in which CaCO_3 is the only carbonate represented.

below. The carbon dioxide formed by this reaction would augment the small amount already present in solution.

If aluminum sulphate were present in considerable amount it may have reacted in the same manner as the ferric sulphate and have been precipitated in the presence of sufficient silica to form kaolin. The greatest argument for this reaction is the intimate association of kaolin with iron oxide in the layers just mentioned. There is also evidence that small amounts of alumina, now present as pockets of zinciferous clay in zinc carbonate ore, were formed at a later stage. The precipitation of the silica in the kaolin may be attributed to the mutual absorptive tendencies of colloidal silica and ferric and aluminum hydroxides. More or less zinc may have been removed from solution by the same influence at this time. The solution, after being depleted of free sulphuric acid and ferric sulphate, would meet the same conditions as those considered in the next paragraph.

Where the solutions had become depleted of free sulphuric acid and ferric sulphate before reaching the carbonate rock, no layer of ferric oxide and kaolin would be formed at first, but replacement of the carbonate rock by zinc carbonate would occur. This reaction has usually been explained by the simple equation



zinc carbonate being precipitated as smithsonite and calcium sulphate passing off in solution. This reaction, however, although it plays an important part in the process, is not sufficient to explain the entire metasomatic process involved in the deposition of the Leadville zinc carbonate ores. Direct replacement of calcium, magnesium, and manganese carbonates by zinc carbonate involves a high percentage of shrinkage; similar replacement of iron carbonate involves less but still considerable shrinkage. Some of the Leadville zinc carbonate ore of the first stage, as shown on page 38, presents some indications of shrinkage, but the amount is so much obscured by later processes of leaching and cavity filling that it can not be even approximately measured. Other specimens of the gray ore which show little or no evidence of leaching contain no pore spaces large enough to be detected with the high powers of the microscope, and the only evidence of shrinkage is the presence of microscopic fractures containing veinlets of smithsonite. The metasomatic process in this material, as shown on page 38, evidently proceeded by infiltration of the solution along the boundaries of the original carbonate grains and replacement of them from the boundaries inward, leaving a very small amount of indeterminate material (unreplaced carbonate?) in the center of each grain. The only conclusion warranted by such inconsistent evidence is that some shrinkage may have been developed during replacement but did not develop everywhere in an amount sufficient

to correspond to the effects of a direct molecular replacement of dolomite or manganosiderite by the gray zinc carbonate ore.

This problem in metasomatism has been discussed by Lindgren,¹ who states:

Replacements of limestone by smithsonite within the rigid rocks are quite common, and in this case the mineral often reproduces exactly the texture of the original rock, even to the most minute details; the resulting secondary zinc mineral is compact and at least not more porous than the original limestone. If this replacement were effected according to a chemical equation, be it by substitution of zinc for calcium in carbonate or by interchange of zinc sulphate and calcium carbonate, a reduction in volume should necessarily be expected. It does not take place provided the metasomatic action goes on within the mass of the rock itself.

It is therefore necessary to look to the mineralogic evidence in the ores for suggestions as to the metasomatic processes that took place. This evidence, presented in the ore descriptions, shows that both manganosiderite and dolomite were replaced by the gray zinc ore, also that after replacement of manganosiderite by ferruginous smithsonite had ceased fractures and other openings were partly or completely filled by smithsonite relatively free from iron.

The descending zinc solutions, depleted of free sulphuric acid and ferric sulphate and most or all of their alumina, contained principally zinc and ferrous iron, with minor amounts of manganese, alkalies, and alkaline earths, chiefly as sulphates and to a minor extent as bicarbonates. Silica was also present. The conditions of chemical equilibrium that exist when so complex a solution attacks the complex carbonate rock manganosiderite can be only roughly inferred from experimental data on relatively simple solutions and compounds. Lack of solubility is the predominating factor in determining the order of separation of the products of such a reaction.² The composition of the gray ore is proof that under the conditions here discussed zinc carbonate was the least soluble product. It is therefore concluded that the zinc in solution as sulphate replaced the bases of the manganosiderite, and that the zinc in solution as carbonate was also precipitated. Precipitation of zinc as smithsonite thus proceeded either until the manganosiderite was completely replaced or until the total zinc in solution became exhausted.

Any shrinkage due to replacement by reaction between zinc sulphate and manganosiderite is believed to have been compensated by simultaneous precipitation of the zinc carbonate from solution, as long as the supply of zinc and the carbonate radicle remained. If the supply was insufficient to compensate fully for shrinkage, a corresponding amount of shrinkage space in the gray ore must have

¹Lindgren, Waldemar. The nature of replacement: *Econ. Geology*, vol. 7, p. 530, 1912.

²Johnston, John, and Niggli, Paul. The general principles underlying metamorphic processes: *Jour. Geology*, vol. 21, p. 506, 1913.

resulted. This space may later have been filled by precipitation from a new supply of solution, or modified, if not obliterated, by the effects of oxidation.

The constituents removed from the manganosiderite by this process, thus became, with the sulphate radicle, the principal constituents in solution and were presumably removed from the manganosiderite zone. Whether or not they could have reacted with and replaced dolomite is a question on which the writer has no definite evidence. The manganese and magnesium in the manganosiderite were evidently more soluble, or replaceable, than the iron, as shown by comparison of the analyses on page 47.

The replacement of iron carbonate by zinc carbonate is not in accordance with certain experimental data. Knopf,¹ in his description of zinc carbonate deposits at Cerro Gordo, in the Inyo Mountains of California, cites experiments by R. C. Wells that showed ferrous carbonate to be less soluble than zinc carbonate; but more recent experiments by Mr. Wells² have shown that the relative solubility or precipitability of the two carbonates differs according to the precipitant used. Thus if sodium carbonate is used in a sulphate solution of the two metals, zinc (carbonate) is precipitated before iron (carbonate); if sodium bicarbonate is used, the order is reversed. The precipitants, or replaced compounds, of the Leadville zinc ores were carbonates, not bicarbonates, and this fact in the light of Wells's experiments may be of some significance.

That both zinc and iron and possibly manganese are similarly precipitated by magnesium and calcium carbonates is shown by the composition of the zinc carbonate ores which have replaced dolomite.³ In this case zinc, iron, and manganese carbonates were precipitated together, in varying proportions, which depended no doubt on their proportions in the solution.

This isomorphous character of the carbonate ore is of interest. The fact that the gray carbonate ore, although free from visible microscopic inclusions of manganosiderite, contains about 14 per cent of ferrous carbonate and smaller amounts of manganese, magnesium, and lime carbonates suggests that replacement of these carbonates by zinc carbonates can extend up to a certain limit but not to their complete elimination. The same feature may have been shown by the ore that replaced dolomite or limestone, but oxidation has obscured the evidence. The ratio of calcium carbonate to other carbonates in

¹ Knopf, Adolph, Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 840, p. 107, 1914.

² Personal communication.

³ No unoxidized carbonate ore replacing dolomite was seen by the writer at Leadville, but the ferric and manganese oxides in the brown ore are mostly or wholly the result of oxidation in place of gray (ferrous) zinc carbonate. In the Tintic district, Utah, the writer found gray zinc-iron carbonate ore replacing practically pure limestone (Econ. Geology, vol. 9, pp. 2-3, 1914).

these ores is misleading, owing to the presence of calcite fillings of fractures and vugs of later origin than the replacement ore.

The progress and behavior of the solutions after deposition of the zinc carbonate could not be adequately studied underground, as the mine workings do not generally follow watercourses beyond the limits of ore bodies. The few such watercourses seen were stained by iron and manganese oxides, but these could hardly have been deposited directly from the waters that deposited the gray zinc ore. The waters after the replacement of manganosiderite must have been sulphate waters containing principally iron and manganese, with some magnesium and small amounts of several other elements. It seems quite possible that they could cause a replacement of dolomite by manganosiderite, but no such replacement is known, and it is doubtful if such a secondary manganosiderite could be distinguished without microscopic study from the primary manganosiderite, which is clearly an intimate associate of the sulphide ores. It is doubtful if the neutral sulphate waters could cause any other chemical action. They would presumably pass on to ground-water level, if they had not already reached it, enriching the ground water in sulphates.

The relation of ore deposition to ground-water level is discussed on pages 64-66, where it is concluded that the gray zinc carbonate ore was deposited close to if not below water level. In this connection the following statement by Lindgren¹ is of interest:

Replacement by equal volume demands the nicest balance between solution and precipitation and takes place when the rock is permeated by stagnant or slowly moving solutions.

These conditions are satisfied below ground-water level and probably in the zone just above it. In arid regions similar replacement deposits are found well above the present ground-water level and are to be attributed either to the existence of a higher water level when replacement occurred, to local impounding of water above an impervious stratum, or to gradual exhaustion of the descending waters by permeation of the rock, with resulting slow movement and supersaturation, thus producing conditions of chemical equilibrium essentially the same as those already considered. The abundant precipitation at Leadville and the presence of sulphide bodies above gray zinc carbonate ore favor the conclusion that deposition of the zinc carbonate bodies on Carbonate Hill below the surface of ground water was quite possible. The ground-water level in fact may have aided the geologic structure in the concentration of these great bodies. In other places—for example, in Iron and Rock hills—deposition took place above the water level, the concentration and the size of the ore bodies being determined by the amount of zinc and other ele-

¹ Lindgren, Waldemar, *The nature of replacement*: Econ. Geology, vol. 7, p. 531, 19

ments in solution and by the rock structure, which influenced the slow or rapid movement of the descending solutions and the degree to which they could permeate the rock.

SECOND STAGE.

It is not to be supposed that the processes of solution, transfer, and deposition already described were sharply separated in all respects from those that remain to be considered. The oxidation of zinc blende was accompanied by simultaneous oxidation of some pyrite and a little galena, and the greater the amount of pyrite oxidized the greater the amounts of iron sulphates that took part in the different reactions; but the much greater susceptibility of zinc blende to oxidation caused its practically complete removal while large amounts of the other two sulphides remained. The first stage, marked by transfer and redeposition of the zinc, is thus distinct from the second stage, which was characterized by oxidation of the remaining pyrite and galena and by a working over of the newly formed zinc carbonate bodies.

The oxidation of the remaining pyrite, as before, caused generation of sulphuric acid and ferric sulphate; the oxidation of galena to sulphate and finally to carbonate generated additional sulphuric acid. The presence of considerable amounts of jarosite and plumbojarosite, however, gives proof that a part of the iron sulphates were deposited without further reactions of present significance and that not all the galena was finally changed to carbonate. The amount of sulphuric acid and ferric sulphate which succeeded in reaching the zinc carbonate bodies therefore represented only a part of the quantity of pyrite and galena oxidized.

The sulphuric acid, on attacking the ferruginous zinc carbonate decomposed it, taking zinc and iron sulphates into solution. The iron sulphate, if free oxygen were present, oxidized to ferric sulphate, which, with the ferric sulphate already in solution, in turn attacked and replaced more of the zinc carbonate and was deposited itself as hydrate or hydrous oxide, thus forming or adding to the layer of iron oxide and kaolin at the top of the ore body. The zinc thus removed was carried in solution until it could again attack and replace manganosiderite or dolomite.

The principal work of the second stage, therefore, was a slight downward migration of the zinc carbonate bodies, material removed from their upper parts being added to their lower parts. The extent of migration obviously depended on the amounts of pyrite and galena oxidized.

THIRD STAGE.

The third stage includes the operation of those processes which have been active since the decomposition of the original sulphides. The principal agents were oxygen and carbon dioxide, which, as lowering of the surface by erosion progressed, became more and more abundant.

Oxygen on reaching the gray carbonate ore oxidized the iron and manganese, causing the formation of red or brown ferric oxide and the zinc-manganese oxide, hetaerolite, the zinc carbonate recrystallizing in a relatively pure state. The iron oxide, to judge from the many specimens of brown ore studied, tended to remain in place, while the new smithsonite and hetaerolite migrated short distances to fractures and other openings to form druses or complete fillings.

This process shows that the smithsonite and hetaerolite were to some extent soluble in the solutions, and that although they were for the most part quickly redeposited, small amounts of them may have been carried for considerable distances. The free carbon dioxide in the water also had a tendency to dissolve the carbonate ore and carry the zinc as bicarbonate, the iron and manganese separating out as oxides. The combined effect of the oxygen and carbon dioxide was to induce a slow downward migration of the zinc carbonate bodies and a corresponding thickening of the layers of iron oxide and clay at their tops.

After the exhaustion of carbon dioxide to a certain degree silica became the active acid radicle, uniting with zinc to form calamine, the latest of the more abundant zinc minerals. The character of different calamine aggregates shows that the zinc and silica were for the most part carried in solution and the calamine was deposited in openings as a result of supersaturation; on the other hand, replacement of smithsonite by calamine shows that a part of the zinc was derived in place and the silica introduced in solution. The source of the silica is to be referred especially to the porphyry overlying the original sulphide bodies. Small amounts of silica may also have been derived from the gangue of these ore bodies and from the original carbonate rocks.

The conditions of equilibrium governing the deposition of calamine are not well understood.¹ It is evident from paragenetic study that calamine can not form until smithsonite (the late drusy form) has finished crystallizing; on the other hand, it is also evident that

¹ Since this paragraph was written experiments to throw light on the conditions affecting the deposition of calamine have been made by Y. T. Wang (The formation of the oxidized ores of zinc from the sulphide: Am. Inst. Min. Eng. Bull., September, 1915, pp. 1988-1991). He found that calamine is soluble in water containing carbon dioxide and even more soluble in water containing bicarbonate of zinc as well. These results agree with the fact that calamine at Leadville is deposited after smithsonite.

calamine can, under certain conditions, replace smithsonite. Why smithsonite is the less soluble in one case and the more soluble in the other is not clear. There is no reason for supposing that silica was not present while the smithsonite was being deposited. A reasonable inference is that crystallization of smithsonite, once started, continued for a time after the equilibrium point was passed, and that the smithsonite was later redissolved by the now more stable calamine. Another conjecture is that, as the solution, through prolonged permeation, became more concentrated, silica superseded carbon dioxide as the stronger acid radicle—in other words, whereas smithsonite was the more insoluble mineral in the dilute solution, calamine was the more insoluble in the concentrated solution.

The occurrence of small amounts of zinciferous clay closely associated with calamine shows that the two were deposited at about the same time. These small amounts of clay may be attributed to alumina, which is commonly present with silica in mine waters of the oxidized zone and was derived from the same sources; but in this case the occurrence of the clay as one of the latest minerals is rather surprising, especially as the waters that deposited it appear to have been practically free from sulphates. Some of the clay however, has evidently resulted from chemical precipitation and suggests that aluminum can be held in solution until the waters become concentrated by depletion, when, in the presence of silica and zinc, it is precipitated as zinciferous clay.

Another interpretation is that the clay was in reality precipitated at an earlier stage and carried in suspension for indefinite distances until finally it was deposited in openings where the waters became stagnant, the zinc content being due to replacement of the aluminum in the clay. This suggestion could be applied to the clay fillings in fractures and fissures. Such fillings may have been formed during the first two (sulphate water) stages, and if they were the chemistry of deposition could be regarded as generally similar to the processes outlined in the preceding pages.

Failure to find any conspicuous occurrences of hydrozincite prevents an adequate discussion of its place and significance in the genesis of the Leadville deposits. The writer, in his study of the Tintic zinc ores,¹ found that hydrozincite as a rule followed the drusy smithsonite and therefore belonged to the same period of crystallization as calamine. This paragenetic relation is in accord with experimental evidence,² which shows that when carbon dioxide

¹ Econ. Geology, vol. 9, pp. 3, 7, 1914. Where hydrozincite in the Tintic district alternated with drusy smithsonite, the later smithsonite was evidently deposited from a new supply of solution, and this was in turn followed by renewed deposition of hydrozincite.

² Ralkow, P. N., Weitere Untersuchungen über die Einwirkung der Kohlensäure auf die Hydrate der Metalle: Chem. Zeitung, vol. 31, p. 55, 1907.

is present in the solution in excess the carbonate of zinc, smithsonite, will crystallize, but that when carbon dioxide is not in excess the basic carbonate, hydrozincite, will crystallize. This principle applied to the waters at Leadville would imply that as the solutions diminished in volume, owing to their spreading along fractures or to permeation through the ore bodies, they lost their excess of carbon dioxide. Smithsonite therefore would cease to form, and the remainder of the zinc carbonate would crystallize as hydrozincite. According to this principle, hydrozincite should be found coating druses of smithsonite and lining fractures below the limits of smithsonite deposition, also as a local alteration product where water containing no free carbon dioxide succeeded in causing recrystallization of smithsonite.¹

The aurichalcite in the Ibex mine accords with this interpretation. The aurichalcite was deposited at the same time as calamine, and both were formed later than drusy smithsonite. Evidently the solution, locally impounded in cavities in the ore, lost its excess of carbon dioxide. The copper and a corresponding amount of zinc then crystallized as the basic carbonate, aurichalcite, and the rest of the zinc went to form calamine. Any excess of silica over that required to form calamine was deposited as opal, chalcedony, or quartz coating or inclosing the calamine crystals.

After the waters had become depleted of zinc carbonate and silicate calcite was deposited in small amount, though only in a few places, as the final product of the third stage. As nicholsonite and aragonite were not found within the ore, they can not be assigned to a definite place in the sequence. Both minerals crystallized in openings in limonite, and from their mode of occurrence would appear to belong to the later part of the third stage of deposition—that is, to the calamine-calcite period—but their relations to calamine, hydrozincite, aurichalcite, and calcite are not known.

The third stage of transfer and redeposition is still in progress. Remnants of gray carbonate ore are undergoing oxidation, and the other zinc minerals are doubtless slowly forming at their expense. These minerals also are being subjected to further leaching and redeposition, and even calamine, the latest of the abundant zinc minerals, may be found in places with corroded surfaces, which signify that slow leaching and continued downward migration are still going on.

SUMMARY.

The detailed discussion of genesis may be briefly summarized as follows:

¹ Since this statement was written Philip Argall (*Mtn. Mag.*, vol. 10, fig. 4, p. 285, 1914) has published an illustration of a specimen taken from a fissure cutting the lower beds of White limestone in the Maid of Erin mine. The specimen consisted of fibrous (drusy) smithsonite covered by a coating of hydrozincite an eighth of an inch thick.

In the first stage ferruginous zinc blende (marmatite) was decomposed by sulphate waters, which also contained carbon dioxide. Where the solutions containing zinc and iron sulphates and smaller quantities of other salts passed through porphyry any free sulphuric acid and ferric sulphate decomposed sericite and feldspar and later deposited the alumina, silica, and zinc as zinciferous clay, either along fissures in the porphyry or by replacing limestone just beneath the porphyry. Where the zinc solutions passed from the sulphide body into limestone any free sulphuric acid at once became neutralized and ferric sulphate was precipitated as ferric hydrate, which replaced the limestone and formed part or all of the characteristic layers that separate the zinc from the lead-silver stopes. If no free sulphuric acid or ferric sulphate was present, no such layer was formed at this time. The neutral solution then caused replacement of carbonate rock, both manganosiderite and dolomite, by gray smithsonite. In the manganosiderite greater proportions of magnesia and manganese than of iron carbonates were replaced. Deposition of the smithsonite took place, at least in part, not so much by direct reaction between the carbonates and a molecularly equivalent amount of zinc sulphate as by a volume for volume interchange. In the replacement of dolomite the magnesia and lime appear to have been replaced simultaneously by zinc and iron carbonates. The replacement of the carbonate rocks was effected by stagnant or slowly moving solutions, which in the northern part of Carbonate Hill may have been close to or even below the level of ground water. Elsewhere the replacement occurred well above the water level.

The second stage was characterized by decomposition of the pyrite and galena that survived the first stage. The resulting sulphuric acid and ferric sulphate that reached the newly formed zinc carbonate bodies tended to leach and replace their upper portions, with a corresponding thickening of the iron oxide layers at their tops, and to remove the dissolved materials to the lower ends of the ore bodies, where additional replacement of carbonate rock could occur. The final result of processes active during the second stage was a greater or less downward migration of the zinc carbonate bodies, the extent of migration depending on the amount of sulphuric acid and ferric sulphate available at any particular place.

The third stage includes the changes that took place after the sources and supplies of sulphuric acid and ferric sulphate had become practically exhausted, leaving carbon dioxide and oxygen as the principal active agents. These attacked the gray zinc carbonate ore, oxidizing its iron to red or brown ferric oxide and its manganese and some zinc to hetaerolite and recrystallizing a part of the remaining zinc carbonate into drusy smithsonite. Although these changes were mostly brought about with very little transfer of material,

there was probably a slight tendency to downward migration of the ore bodies and corresponding thickening of the overlying iron oxide layers. After the work of oxygen and carbon dioxide had been mostly accomplished and the excess of carbon dioxide had escaped, small amounts of aurichalcite and hydrozincite were formed. At about the same time silica succeeded carbon dioxide as the dominant acid radicle and caused the deposition of calamine, mostly as cavity fillings but to a minor extent replacing smithsonite. Where aluminum was locally an abundant constituent of the solutions at this period small amounts of zinciferous clay were deposited in cavities along with or in place of calamine. If silica was present in excess, small amounts of opal, chalcedony, or quartz were deposited after the calamine. Calcite and probably also aragonite and nicholsonite were deposited later than the calamine, representing the latest of the succession of minerals in the oxidized zinc ore bodies. Oxidation of the third stage, however, is still in progress.

PROSPECTING FOR BODIES OF OXIDIZED ZINC ORE.

The more consideration one gives to the factors chiefly concerned in the genesis and distribution of the oxidized zinc ore bodies, the more hesitant is he likely to become in any attempt to predict the location of undiscovered bodies. It is obvious that the zinc bodies are intimately associated with the old lead-silver stopes, but their exact positions, shapes, and sizes depend upon too many variable factors to be determined without actual prospecting. In the first place, the distribution of zinc blende in the original sulphide bodies was very irregular, as it is in the sulphide bodies now being mined.

In some ore bodies zinc blende although abundant, may have been accompanied by even more abundant pyrite, as in most of the present sulphide bodies. In such deposits the effects of the first and second stages of oxidation may have removed the bulk of the zinc a considerable distance from the corresponding lead-silver body, the intervening space being occupied by iron oxide or "contact matter." Whether such prolonged transfer would result in greater concentration or dispersion of the zinc would depend upon local structures. Local concentrations may be represented by some of the Chrysolite bodies (fig. 7, p. 57) found a considerable distance below the stopes shown in Emmons's sections and just above the upper contacts of porphyry sills.¹

In other ore bodies a shoot of zinc blende may have existed side by side with one of pyrite, and oxidation with downward migration may have resulted in the formation of zinc carbonate and iron oxide

¹ Emmons, S. F., *Geology and mining industry of Leadville, Colo.*: U. S. Geol. Survey Mon. 12, atlas sheets 81 and 82, 1886.

bodies side by side. Oxidation of manganosiderite beside or even beneath the zinc carbonate bodies may also have yielded iron oxide or manganese-iron oxide bodies, but oxidation beneath the zinc ores was doubtless of relatively infrequent occurrence and small extent.

At some places the rock underlying original sulphide bodies may have contained much siliceous matter and correspondingly little carbonate material. In such places the smithsonite, deposited by replacement of the carbonate content, may have formed low-grade ore bodies of considerable extent or local shoots where fissuring or shattering permitted thorough permeation of the elsewhere relatively impervious rock. Descending solutions from siliceous ore bodies may have been unusually rich in silica and alumina and deposited them in some form along with the zinc, thus giving ore of low grade. Such conditions may account for the characteristics of the ore bodies in the Tucson mine and of some ore bodies in the Chrysolite mine.

The influence of local structure has been illustrated on pages 54-56, and only summarized statements need be made here. Faults and strong fissures, if filled with impervious material or if bringing impervious or nonreplaceable beds opposite replaceable beds, may serve to impound the solutions and develop an ore body of unusual thickness; faults and fissures of similar magnitude, if open and very pervious, may serve to concentrate the flow of solutions along them and give rise to deposits of general veinlike form. If solutions traveling along open fissures pass beyond the limits of the carbonate rocks before effecting much replacement, it is probable that no workable deposits will be formed by them. Impervious rock layers, such as the quartzites and porphyries, may confine replacement to the limestone above them; but the same rocks, if fractured, may allow the solutions to pass into or through them. Where solutions penetrate Cambrian quartzite or thick masses of porphyry in this manner their zinc contents are not likely to be concentrated into workable deposits. If solutions find their way into a large body of rock which is chemically replaceable but only slightly permeable and which is not immediately underlain by some impervious bed, the solutions are likely to become dispersed and to yield an extensive body of low-grade ore or a series of shoots too small for profitable mining.

These many and varying conditions should convince operators that the more they know of the significance of structural details of their ground the more intelligently can they prospect for zinc ores. They should realize that large bodies of high-grade ore are to be found only where the original supply of zinc, local structural conditions, and the composition of the country rock have all been favorable. The area covered by the numerous and extensive oxidized lead-silver

stopes in the district, extending from the western edge of the Downtown section eastward to Ball Mountain and from Fryer Hill southward to Rock Hill, is legitimate prospecting ground for oxidized zinc ores, but it remains for those most familiar with the details of individual mines or claims to formulate the best methods of prospecting. Furthermore, especially where ground has been abandoned for a long time and detailed knowledge of it is slight, prospectors should be ever on the lookout for new and unexpected evidence and should modify their methods accordingly.

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JOHN BARTON PAYNE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Bulletin 682

MARBLE RESOURCES OF SOUTHEASTERN
ALASKA

BY

ERNEST F. BURCHARD

WITH A SECTION ON

THE GEOGRAPHY AND GEOLOGY

BY

THEODORE CHAPIN



WASHINGTON
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PREFACE.

By ALFRED H. BROOKS.

Alaska marble was first used, long before the coming of the white man, by the natives, who carved utensils and ornaments from some of the more highly colored varieties. The Russian occupants of Alaska gave no heed to the marble, though they may have utilized a few slabs for tombstones. The marbles of southeastern Alaska were among the first of the mineral deposits of the Territory to be mentioned in the official reports of the United States Government. For many years these marbles excited no interest, for in spite of their favorable location on tidewater there was no market for them and accordingly they had no value. Probably some time in the early nineties a little marble was quarried on Ham Island, in the Wrangell district, and worked up into tombstones, which were sold at localities near by. These tombstones were in considerable demand among the natives, who learned their use from the white man and substituted them for the crudely carved wooden totems.

It was about 1896 that the first thought was given to opening the Alaska marble deposits on a commercial scale, for by this time the rapid growth of the cities of the west coast had made a demand for ornamental and building stone. After some years of prospecting on the deposits on the northwest side of Prince of Wales Island, a quarry was opened near Calder, and shipments were begun in 1902. Since 1904 there has been a steady increase in the marble output of Alaska, which, however, has practically all come from a few quarries in the Shakan-Calder region of the Ketchikan district. Although, as this report shows, marble is widely distributed in southeastern Alaska, its development has thus far been limited to one general region.

Previous to Mr. Burchard's investigation of the marbles of southeastern Alaska they had received only scant attention by the Geological Survey. A few of the marble deposits had been visited by geologists, but the examinations were only cursory and incidental to the study of other problems relating to geology and mineral resources. Mr. Burchard deserves great credit for having procured

in two short field seasons so large an amount of data relating to the marbles of this region. He has been able to indicate in a general way the areas containing marble deposits. Detailed information regarding the distribution and extent of the deposits will be possible only after complete areal and structural surveys have been made. This work will be undertaken as soon as circumstances permit. Meanwhile this report will serve a valuable purpose in presenting a complete statement of present knowledge concerning this valuable mineral resource of the Territory.

MARBLE RESOURCES OF SOUTHEASTERN ALASKA.

By ERNEST F. BURCHARD.

INVESTIGATIONS.

Studies of the marbles and other structural materials of southeastern Alaska were made for the United States Geological Survey by F. E. and C. W. Wright in 1904, 1905, and 1906, and the results were published in Survey bulletins.¹ Between 1908 and 1912 nothing was added to the reports on the subject.

In the autumn of 1912 the writer made an examination of the marble areas on Prince of Wales, Kosciusko, Marble, Orr, Tuxekan, Heceta, Ham, and Revillagigedo islands, and in the autumn of 1913 this work was extended to deposits on the mainland bordering Blake Channel, Stephens Passage, and Glacier Bay, on several islands in Glacier Bay, and on Chichagof and Admiralty islands. About nine weeks in all was spent in the field work of the two seasons, which involved cruising along about 1,500 miles of shore line in small gasoline launches. The results of the work completed in 1912² and notes concerning the deposits examined in 1913 lying north of Frederick Sound³ were published in Survey bulletins. The field seasons of 1915 and 1916 were spent by Theodore Chapin in geologic work in southeastern Alaska, and he gathered additional notes concerning marble deposits on Dall, Long, and Revillagigedo islands. The more important of these deposits have been described by Chapin.⁴ Practically all the available data on marble deposits in southeastern Alaska have been brought together in the present bulletin.

The manuscript for this bulletin was submitted in October, 1916, but owing to the large number of publications which were expedited

¹ Wright, F. E. and C. W., Economic developments in southern Alaska: U. S. Geol. Survey Bull. 259, p. 68, 1905; The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 191-198, 1908. Wright, C. W., Nonmetallic deposits of southeastern Alaska: U. S. Geol. Survey Bull. 284, pp. 55-57, 1906; A reconnaissance of Admiralty Island: U. S. Geol. Survey Bull. 287, p. 154, 1906; Nonmetalliferous mineral resources of southeastern Alaska: U. S. Geol. Survey Bull. 314, pp. 73-77, 1907; The building stones and materials of southeastern Alaska: U. S. Geol. Survey Bull. 345, pp. 116-122, 1908.

² Burchard, E. F., Marble resources of Ketchikan and Wrangell districts: U. S. Geol. Survey Bull. 542, pp. 52-77, 1913.

³ Burchard, E. F., Marble resources of Juneau, Skagway, and Sitka districts, Alaska: U. S. Geol. Survey Bull. 592, pp. 95-107, 1914.

⁴ Chapin, Theodore, Mining developments in southeastern Alaska: U. S. Geol. Survey Bull. 642, pp. 100-104, 1916.

on account of the European war, coupled with a shortage of men, the preparation of the illustrations for the printer was necessarily deferred until the summer of 1919.

The petrologic character of the intrusive and metamorphic associated with the marble deposits was determined by J. B. M. and petrologic studies of many of the marbles in thin sections made by T. N. Dale and G. F. Loughlin, of the United States Geological Survey.

The Survey herewith expresses its appreciation of the co-treatment extended to its representatives by Mr. F. E. Bronson, lecturer of customs at Wrangell; the Vermont Marble Co., the Mission Marble Works (later the Mission-Alaska Quarry Co.), Alaska Marble Co., the El Capitan Marble Co., the Alaska-Si-rock Marble Co., Messrs. Woodbridge & Lowery, Frank Spald, Walter C. Waters, M. D. Ickis, and many others interested in development of the marble resources of southeastern Alaska.

GEOGRAPHY AND GEOLOGY.

By THEODORE CHAPIN.

GEOGRAPHY.

LOCATION AND EXTENT.

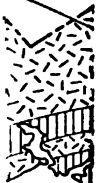
The region popularly known as southeastern Alaska comprises the panhandle extending from Dixon Entrance northwestward to Mount St. Elias. It is bounded on the northeast by British Columbia and Yukon Territory and on the southwest by the Pacific Ocean, forming a strip 400 miles long and 100 to 150 miles wide, with a narrow extension on the northwest 100 miles long and 25 to 50 miles wide. That portion concerned in the present sketch, as shown on the index map (Pl. I), extends southeastward from Mount Fairweather. It comprises a mainland belt and a bordering group of islands known as Alexander Archipelago. The larger islands forming this group named in order from north to south, are Admiralty, Chichagof, Baranof, Kupreanof, Kuiu, Revillagigedo, Prince of Wales, and Dall islands. Other smaller islands important on account of their deposits of marble are Ham, Long, Kosciusko, Marble, and Orr islands.

RELIEF AND DRAINAGE.

Southeastern Alaska is a very mountainous region, lying within the Pacific Mountain system, which as defined by Brooks¹ includes a broad zone of ranges parallel to the southern coast of Alaska. In southeastern Alaska the dominant feature of this province is the

¹ Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, p. 14, 1902.

U. S. GEOLOGICAL SURVEY
Cape Ommaney



4d. Prince of Wales I., east of Dolomi
4e. Prince of Wales I., Dickman Bay
4f. Mainland, Lake Victoria
4g. Mainland, north end Blake Channel
4h. Blake Island



Coast Range, a rugged mountain mass extending along the northeastern boundary for its entire length. The Alexander Archipelago is made up of a mountain mass composed of a number of ranges not sharply differentiated from the Coast Range and sometimes regarded as a southeastern extension of the St. Elias Range.¹ The entire region gives the impression of a high plateau deeply dissected by erosion. It is veined by an intricate system of waterways; the islands are separated from the mainland and from one another by deep channels from which fiords penetrate both islands and the mainland, making a very sinuous coast line and numerous inlets and bays.

The region is one of marked relief and very rugged topography. The land rises abruptly and in many places precipitously from the water's edge, reaching altitudes of several thousand feet a short distance from the shore.

The four main rivers of southeastern Alaska, the Alsek, Chilcat, Taku, and Stikine, rise in British Columbia and flow across the coast ranges to the sea. The islands are drained by small streams.

GLACIATION.

Southeastern Alaska shows unmistakable evidence of very general glaciation which affected all but the highest parts of the region and produced a characteristic topography. Among the many features of glacial erosion that are developed to a remarkable degree the most conspicuous are the interdigitating fiords that penetrate the entire region. The most prominent of these fiords is Lynn Canal, which with its extension, Chatham Strait, forms a nearly straight channel for over 220 miles. Portland Canal, another remarkable fiord, is about 100 miles in length. Other marks of glacial sculpture are the cirque basins, hanging valleys, U-shaped valleys, polished and grooved surfaces, and lakes with rock-rimmed basins deepened by glacial scour. Glacial deposits are uncommon except in the vicinity of the present glaciers, although erratic boulders occur in places.

Glaciers occur on the mountain slopes of the mainland, and at least one small one has been observed on Admiralty Island. North of Stikine River many of the glaciers reach the sea and discharge ice into the fiords and bays.

CLIMATE.

The climate of southeastern Alaska is characterized by moderate temperature and abundant precipitation. The winters are comparatively mild, and the ports are open to navigation the year round. Near sea level the first frosts occur about September or October

¹ Brooks, A. H., *The geography and geology of Alaska*: U. S. Geol. Survey Prof. Paper 45, p. 29, 1906.

and the last in May or June. The thermometer seldom falls to zero. The snowfall is slight except on the mountains, and the precipitation is mostly in the form of rain, which is heaviest during the fall and winter months. The prevailing winds blow from the southwest; a southeast wind is indicative of storm, and a northwest wind usually brings fair weather. The heavy precipitation, although occasioning considerable inconvenience in travel and prospecting, is a very valuable asset in providing water power, which is being developed more fully each year for use in mining and milling.

TIMBER AND VEGETATION.¹

The greater part of southeastern Alaska lies within the Tongass National Forest, formerly known as the Alexander Archipelago National Forest. Because of the heavy precipitation and the long-growing season the hillsides from the sea level up to the line of permanent snow, from about 2,000 to 3,000 feet above the sea, are covered with vegetation. An estimate of the relative abundance of the conifers of the forests is given below:

	Per cent.
Western hemlock (<i>Tsuga heterophylla</i>).....	60
Black hemlock (<i>Tsuga mertensiana</i>)-----	
Sitka spruce (<i>Picea sitchensis</i>)-----	25
Western red cedar (<i>Thuja plicata</i>)-----	7
Yellow cedar (<i>Chamaecyparis nootkaensis</i>)-----	5
Lodgepole or jack pine (<i>Pinus contorta</i>).....	3
White balsam fir (<i>Abies balsamea</i>)-----	

Hemlock is the most abundant, and of the two varieties noted the western hemlock is much more plentiful. The hemlock is less susceptible than spruce to the borings of the teredo worm, and for this reason and on account of its greater weight it has been in much demand for piles used in fish traps and in wharves and docks. For this purpose it is well adapted, tapering but little in the length required for piles. During the year ending June 30, 1915, about 2,250,000 linear feet of hemlock was cut for piling in southeastern Alaska. Hemlock is also used extensively for planking and is better adapted for this use than fir, as it does not splinter so badly and lasts longer. A great amount of planking is used in wharf, road, and tram construction. The streets of most southeastern Alaska towns are built of planks placed upon piling.

For general purposes spruce has found the widest use. It grows to fine proportions, reaching 200 feet in height and 4 feet in diameter 100 feet above the butt. Its yield averages 2,500 board feet to the tree, and exceptional trees yield 20,000 feet. On account of its toughness and lightness the Sitka spruce has recently come into

¹ The writer is indebted to Mr. W. G. Weigle, forest supervisor of Alaska, for information regarding the timber of southeastern Alaska.

great favor for airplane construction and is used in England and France, as well as in the United States.

The red cedar is used for shingles and for boat timber. The yellow cedar also is used in boat construction and is suitable for furniture and pattern making, but it is not easily obtained, as little of it grows below an altitude of 500 feet above sea level.

Among other trees common to this region may be noted mountain ash, cottonwood, quaking aspen, crabapple, willow, and alder. From sea level to an altitude of 1,500 feet or so the forests contain a dense undergrowth of berry bushes and other shrubs that form in places an impassable barrier, through which trails must be cut. The most objectionable of these shrubs is the devil's club, a luxuriant bush whose stalks and stems are thickly covered with sharp, fine thorns. Salmonberries are the most abundant and form impenetrable thickets. Huckleberries are plentiful; they include two varieties of blue and one of red berries. The region also contains high-bush cranberries and black currants.

POPULATION AND SETTLEMENTS.

The population of southeastern Alaska is distributed mainly among the mining and fishing centers. Skagway, the northernmost town, is the terminus of the White Pass Railway. Juneau, the Territorial capital, is the distributing center of the north end of southeastern Alaska. Four miles southeast of Juneau is the new town of Thane, and across Gastineau Channel is the town of Douglas, maintained principally by the operations of the Treadwell mine. Sitka, on the west coast of Baranof Island, is the home of the agricultural experiment station and a general supply point. It is of special historic interest as the first capital of Alaska and contains valuable relics of the early Russian occupation. Wrangell and Petersburg are supply centers for the central part of the region and outfitting stations for expeditions up Stikine River. The southern part of the region is served by Ketchikan, the first port of entry in southeastern Alaska and headquarters of the Forest Service. There are also scores of small settlements at or near canneries or mines, to which regular mail and passenger service is maintained and where boat supplies, fuel, food, and clothing can be purchased. Gasoline launches and boats may be hired at any of the larger towns. Freight rates are reasonable, and costs compare favorably with those at Seattle.

ACCESSIBILITY.

Transportation facilities on land are poorly developed. The rugged nature of the land, with its many swampy areas and the heavy growth of brush, as well as the numerous deep fiords and channels

that cut into or separate the islands, precludes the possibility of the extensive construction of railroads, or even of wagon roads, except at unwarranted expense. The need of railroad construction is in large part obviated, however, by the intricate system of waterways which penetrates the entire region, providing excellent highways for deep-sea vessels and numerous deep-water harbors in sheltered bays. Many marble deposits occur near tidewater and on sheltered bays; at less favorable localities the construction of surface or aerial trams is facilitated by a supply of suitable timber near by.

GEOLOGY.

GENERAL FEATURES.

The study of the geology of southeastern Alaska, though not sufficient in detail to admit of accurate mapping, has established certain geologic relations and a general sequence of rock types that is more or less uniform throughout the region.¹

The rocks of this region comprise a variety of both sedimentary and igneous types and their metamorphic derivatives. In age they range from early Paleozoic to Recent. The details of their structural and stratigraphic relations are complex. The older rocks are closely folded and for the most part are disposed in zones whose axes strike about northwest, approximately parallel to the trend of the Coast Range. This system of folding, however, is complicated by an older system, and the combination of the two tends to throw the beds into complex structural relations. The stratigraphic and structural relations are further complicated by overturned folds. With the exception of the more recent formations most of the rocks are more or less metamorphosed, so that their original nature is in large part obscured.

SEDIMENTARY ROCKS.

The Paleozoic rocks, which are grouped and shown with one pattern on the accompanying index map, comprise a number of separate formations that include a great variety of sediments. They may be grouped roughly in two major divisions separated by a marked

¹ The writer has drawn freely from the following published Survey reports concerning parts of the region with which he is not familiar:

Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, 1902; The geographic and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, 1906.

Spencer, A. C., The Juneau gold belt; Wright, C. W., A reconnaissance of Admiralty Island, Alaska: U. S. Geol. Survey Bull. 287, 1906.

Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, 1908.

Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, 1911; The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, 1912; The Sitka mining district, Alaska: U. S. Geol. Survey Bull. 504, 1912.

Emith, P. S., Notes on the geology of Gravina Island, Alaska: U. S. Geol. Survey Prof. Paper 95 pp. 97-105, 1915.

unconformity and differing considerably in amount of metamorphism. The older of these divisions, which probably includes a number of formations, is pre-Devonian. The younger division is Devonian and Carboniferous. The older Paleozoic rocks crop out at several places on Dall, Prince of Wales, Baranof, Chichagof, and Kuiu islands, and along Glacier Bay on the mainland. In the Ketchikan district the oldest Paleozoic rocks may be divided into three conformable terranes, of which one is prevailingly arenaceous, one calcareous, and one tuffaceous. These distinctions, however, are only general, for limestone beds occur throughout the series and thin sheets of tuff are intercalated with all other members of the series.

Unconformably overlying this lower series is a succession of tuffaceous conglomerate and grits, black and green slate, and limestone, with intercalated lava flows and breccias, which probably belong to the older Paleozoic division. These older Paleozoic rocks contain Silurian fossils at a number of places, and in the Ketchikan region they are overlain unconformably by Lower and Middle Devonian rocks. It is thus evident that they are Silurian, and possibly older.

Overlying the older Paleozoic rocks with apparent unconformity are massive conglomerates and arenaceous sediments interbedded with and overlain by gray massive limestone of Lower and Middle Devonian age. The Upper Devonian rocks consist of dark-colored limestones and black cherts associated with basaltic flows and breccias. The Devonian rocks have a wide distribution and have been found on Hotspur Island, a small island near the southern point of southeastern Alaska, on Gravina Island, at various places on Prince of Wales Island, and the small islands off the west coast, and on Chichagof Island.

Carboniferous rocks also are widely distributed in southeastern Alaska and include limestones representing three horizons, one Mississippian and two Pennsylvanian. The lower Carboniferous beds are composed of interbedded limestone and black chert and are very similar in appearance to the Upper Devonian beds, which they appear to overlie conformably. The upper Carboniferous formations are gray to white heavy-bedded massive limestone. Presumably still higher in the Carboniferous section are phyllites and greenstones with beds of dolomitic limestone.

The workable deposits of marble appear to be confined to the Paleozoic limestone beds. The older Paleozoic limestones are all more or less metamorphosed and in places are entirely recrystallized. The Devonian and Carboniferous beds are less metamorphosed and except in the vicinity of intrusive rocks are less crystalline. Some of the best marble deposits, however, occur in the younger Paleozoic limestones, which are in close proximity to granitic intrusives. The formation of the marble thus appears to be due more to contact meta-

morphism than to regional metamorphism, although in many places it was probably due to a combination of both causes. The beds that offer the greatest possibilities of containing valuable bodies of marble are the Paleozoic formation in the vicinity of granitic intrusives. Where the limestone was originally pure the resulting marble is pure and white, but where it was mixed with impurities such as greenstone or other igneous material variegated and colored deposits have been formed, and in searching for either white or ornamental marble these facts should be borne in mind.

The Mesozoic formations, although widely distributed, have a smaller areal extent than the Paleozoic. They comprise Triassic, Jurassic, and Cretaceous rocks. The relation between the Paleozoic and Mesozoic is not well known. In the Ketchikan region an unconformity at the base of the upper Triassic is suggested by a massive conglomerate that contains pebbles of fossiliferous Devonian limestone, but the stratigraphic relations are obscured by an overturned fold in which both Triassic and Jurassic formations are involved with the Carboniferous, so that the younger rocks dip beneath the older ones. A similar overturned fold is suggested by the relative position of Paleozoic and Mesozoic rocks at Juneau. The Triassic and Jurassic rocks comprise conglomerate, black slate and graywacke, augite melaphyres, and tuffs, with intercalated black and green slates. Lower Cretaceous beds of conglomerate, graywacke, and slate occur on Admiralty Island, and similar sediments probably of the same age are found on Gravina Island. The Mesozoic limestones are comparatively thin bedded and as a rule not crystalline. They do not offer as great possibilities for producing deposits of marble as the Paleozoic limestones.

Tertiary sandstone, conglomerate, lavas, and tuffs are exposed at many places on Kupreanof, Admiralty, and Prince of Wales islands. These beds are of interest commercially, as some of the sandstones are coal bearing. They rest unconformably on the eroded edges of older rocks and have suffered comparatively little metamorphism. Fossil-bearing beds among them indicate that they are essentially of Eocene age.

IGNEOUS ROCKS.

By far the most important series of rocks in southeastern Alaska in point of size and in influence on the economic deposits is the assemblage of intrusive granite, diorite, and granodiorite that makes up the central portion of the Coast Range and occupies a broad strip along the northeast boundary of southeastern Alaska and widely distributed areas throughout Alexander Archipelago. The genetic relation of the granite rocks to ore deposition in southeastern Alaska has been universally recognized, and it is of interest to note also

the bearing of these rocks upon the marble deposits. Almost all these deposits occur in the vicinity of intrusive granite rocks, and it is believed that they owe their marmorosis to the influence of the intrusives. This relation of position should serve as a valuable guide to the prospector in his search for marble deposits. The contact influence of the granite intrusives upon other rocks resulted in the formation of schists and gneisses along the borders of the batholiths and in metamorphism of varying degrees around the smaller intrusive masses distributed throughout the region. The intrusions occurred, at least in part, during late Jurassic or early Cretaceous time, but they may have extended over a considerable period. Dike rocks of diabasic and felsitic character are much younger than the granitic intrusives and cut nearly all the rocks of the region.

The flows and associated tuffs are widely distributed and occur in association with sedimentary formations of Paleozoic and Mesozoic age. These rocks, to which, because of their constant greenish color, the convenient field term greenstone is applied, range in composition from andesites to gabbros and in degree of metamorphism from massive rocks to crinkled schists.

Rhyolitic lavas and tuffs are associated with the Tertiary sediments. The youngest rocks of the region are basaltic lavas and tuffs of Recent age. They occur in isolated patches on the mainland east of Behm Canal and on Revillagigedo Island but find their best development in the volcanic cone of Mount Edgecumbe, on Kruzof Island, near Sitka.

ELEMENTARY NOTES ON LIMESTONE AND MARBLE.¹

CLASSIFICATION.

Limestone belongs to the class of rocks known as sedimentary, as distinguished from igneous and metamorphic rocks. True marble is a metamorphic rock. Sedimentary rocks are generally composed of the fragments or materials of older rocks of any class that have undergone disintegration on the surface of the land, but may also include volcanic materials deposited in water.

Metamorphic rocks are sedimentary or igneous rocks that have, in the course of time, become greatly changed in composition and

¹Data on limestone and marble are given in modern textbooks on geology and in the following special works:

Clarke, F. W., *The data of geochemistry*, 3d ed.: U. S. Geol. Survey Bull. 616, 1916.

Crosby, W. O., *Common minerals and rocks*, D. C. Heath & Co., 1906.

Dale, T. N., *Commercial marbles of western Vermont*: U. S. Geol. Survey Bull. 521, 1912.

Kemp, J. F., *Handbook of rocks*, 5th ed., D. Van Nostrand Co., 1911.

Merrill, G. P., *Stones for building and decoration*, John Wiley & Sons, 1903.

Pirsson, L. V., *Rocks and rock minerals*, John Wiley & Sons, 1909.

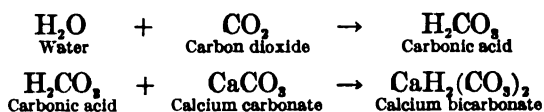
Van Hise, C. R., *A treatise on metamorphism*: U. S. Geol. Survey Mon. 47, 1904.

texture. The chief agents that bring about these changes are pressure, heat, and chemical action, generally at considerable depths below the surface of the earth. By metamorphic agencies limestone is transformed into marble. During the transformation the original bedding of the limestone may become nearly or completely obscured, and the crystalline texture and folded structure characteristic of marble are induced.

ORIGIN OF LIMESTONE.

The sediments that now constitute sedimentary rocks were deposited under water in estuaries, seas, and lakes, on land surfaces, and in cavities and crevices in other rocks. The chief agent in the transportation of rock débris is water in motion, including rain water, streams, currents, and waves. Considerable débris is transported by moving ice in the form of glaciers and icebergs, and small quantities of very fine, light material are carried by the wind. Deposits of material carried as solid particles are said to be mechanical. Deposits formed largely of the remains of organisms are called organic; such deposits include some formed by deposition from solution. Material precipitated from solution without the aid of organisms forms chemical deposits.

Calcium carbonate (CaCO_3), the principal compound in limestone, is slightly soluble in pure water, 1 liter of pure water solution at 8.7°C . containing 0.01 gram of the compound.¹ In water charged with carbon dioxide (CO_2), forming a solution of carbonic acid, calcium carbonate is more soluble and forms calcium bicarbonate. The reactions are as follows:



One liter of water saturated with carbon dioxide contains at 15°C . and zero partial pressure of carbon dioxide 0.385 gram of calcium bicarbonate.² Under natural conditions a less quantity is dissolved, but it is believed that under such pressures as exist at considerable depths below the surface of the earth water will dissolve still greater quantities. Water sinking through the soil meets and dissolves carbon dioxide, which is constantly being given off from decaying vegetable matter. This acidulated water then takes up calcium carbonate from the soil and from the rocks through which it percolates. The water of streams is therefore constantly bringing a supply of dissolved calcium carbonate to the ocean. Evaporation

¹ Seidell, Atherton, Solubilities of inorganic and organic substances, p. 86, New York, D. Van Nostrand Co., 1907.

² Idem, p. 87.

concentrate this material in sea water, and were it not for large quantities of calcium carbonate are constantly being brought about through the agency of marine organisms the sea water would be charged with this salt. Sea water contains about 35,000 parts per thousand, by weight, of mineral matter in solution. The principal solids are shown in the following

Parts in total solids contained in sea water.¹

-----	77.758
-----	10.878
-----	4.737
-----	3.600
-----	2.465
-----	.217
-----	.845
-----	100.000

present in sea water, including a relatively large amount of carbon dioxide, and these tend to increase the solvent power of the water on calcium carbonate.

There is no sharp line of distinction between chemical and organic deposits. Organic deposits are really chemical in the broader sense, but they are termed organic because their precipitation is immediately dependent upon living organisms. Subaqueous inorganic chemical deposits are probably formed mostly in shallow water and include those due to the evaporation of the water and those due to chemical reactions between solutions, resulting in the precipitation of new and insoluble compounds.

Chemical deposits formed in shallow water are chiefly simple precipitates resulting from evaporation. All substances in solution are necessarily precipitated upon complete evaporation of the solvent, but as sea water is rarely saturated with its most abundant salts only a few are precipitated in quantities sufficient to be of geologic significance. The principal deposits formed on incomplete evaporation that are of interest in the present connection are calcium carbonate (CaCO_3 , limestone), calcium sulphate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, gypsum), sodium chloride (NaCl , rock salt), and chlorides and sulphates of potassium and magnesium.

The deposits of calcium carbonate, including shells and coral, have been very much greater than those of calcium sulphate, because marine plants and animals extract calcium carbonate and not calcium sulphate from the sea water for their skeletons and shells, although the water contains more than ten times as much calcium sulphate as

¹ Dittmar, William, *Challenger Rept.*, Physics and chemistry, vol. 1, pt. 2, p. 954.

calcium carbonate. Calcium sulphate is more soluble in natural water than calcium carbonate, but rivers carry much more carbonate than sulphate to the sea, because calcium carbonate is much more abundant on the land.

The secretion of calcium carbonate by organisms does not depend on the quantity of the carbonate contained in the water; it may be carried on when the quantity in solution is very small. The principal deposits of calcium carbonate which have ultimately formed limestone have been made through the agency of plants and animals and consist of oolites, shells, skeletons, coral, bones, and teeth. Some of these deposits show more or less distinctly the fossil remains of the organisms that played so important a part in their formation, but others, on account of the fineness to which the fragments were broken by the waves prior to their consolidation into rock masses, show no trace of their organic origin. Although it is probable that the larger part of the calcium carbonate deposits in the open sea are of organic origin, it is equally probable that in closed seas, in which the conditions are favorable for concentration, direct precipitation of calcium carbonate may take place.

That the influence of bacteria upon the precipitation of calcium carbonate from solution in sea water is of much importance is now recognized. With regard to the formation of the Bahaman and Floridian oolites, Vaughan¹ states:

1. Denitrifying bacteria are very active in the shoal waters of both regions and are precipitating enormous quantities of calcium carbonate, which is largely aragonite.

2. This chemically precipitated calcium carbonate may form spherulites or small balls which by accretion may become oolite grains of the usual size, or it may accumulate around a variety of nuclei to build such grains.

The deduction may be made that all marine oolites originally composed of calcium carbonate, of whatever age, may confidently be attributed to this process.

Walcott² has called attention to the presence of numerous reefs of algal deposits at several horizons in the Newland limestone of the Belt series in Montana, some 9,000 feet below the base of the Cambrian, and of isolated concretion-like forms scattered at various levels in the overlying Spokane shale of the Belt Mountains. Many forms of algal remains occur in these deposits. Some of them are strikingly similar to the fresh-water lake and stream blue-green algal deposits of New York, Pennsylvania, and Michigan; others are

¹ Vaughan, T. W., Preliminary remarks on the geology of the Bahamas, with special reference to the origin of the Bahaman and Floridian oolites: Carnegie Inst. Washington Papers from Tortugas Laboratory, vol. 5, pp. 53-54, 1914.

² Walcott, C. D., Pre-Paleozoic algal deposits (paper delivered before Botanical Society of Washington, Apr. 6, 1915; abstract in Washington Acad. Sci. Jour., Dec. 4, 1915, p. 649).

similar in appearance to the blue-green and green algal deposits of the thermal waters of Yellowstone National Park.

According to Clarke,¹

It is evident that important limestones may be formed in various ways which, however, are chemically the same. Calcium carbonate, withdrawn from fresh or salt water, is laid down under diverse conditions, yielding masses which resemble one another only in composition. An oceanic ooze may produce a soft, flour-like substance, such as chalk, or a mixture of carbonate and sand, or one of carbonate and mud or clay. Calcium carbonate, transported as a silt, may solidify to a very smooth fine-grained rock, while shells and coral yield a coarse structure, full of angular fragments and visible organic remains. Buried under other sediments, any of these rocks may be still further modified, the fossils becoming more or less obliterated, until in the extreme case of metamorphism a crystalline limestone is formed. All trace of organic origin has then vanished, a change which both heat and pressure have combined to bring about, aided perhaps by the traces of moisture from which few rocks are free.

CHARACTER OF LIMESTONE.

Limestone, from which marble is derived, includes rocks of many and widely varying types, differing in origin, color, texture, hardness, structure, and composition. The one property they have in common is that of consisting largely of the mineral calcite or calcium carbonate (CaCO_3) or of the mineral dolomite, a combination of calcium and magnesium carbonates ($\text{CaCO}_3, \text{MgCO}_3$). No natural limestones are chemically pure, however, and few are nearly so. All contain more or less foreign material, either chemically combined or as admixed minerals. The more common of these foreign substances are magnesium carbonate (MgCO_3), ferrous carbonate (FeCO_3), ferrous oxide (FeO), ferric oxide (Fe_2O_3), silica (SiO_2), alumina (Al_2O_3), clay, carbonaceous matter, mica, talc, and minerals of the pyroxene group. The colors and stains commonly noted in limestones are due to the presence of foreign minerals. The light-blue, buff, yellow, pink, red, and brown shades are due largely to iron compounds, and many of the grays and blacks are due to the presence of carbonaceous matter derived from organic remains. Manganese oxides also act as coloring agents.

VARIETIES OF LIMESTONE.

The common varieties of nonmetamorphosed limestone described below are often used as commercial marble. They may be distinguished chiefly by texture.

1. Dense, fine-grained limestone. Rock of this type generally takes a good polish and if of suitable color may be used as marble. Many of the black marbles are simply dense, fine-grained dark-blue

¹ Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616, pp. 555-556, 1916.

limestone. A typical example is the black limestone at Isle La Motte, Vt., which is extensively used for decoration throughout the United States.

2. Crystalline limestone. Limestone of this type generally takes a good polish, and where of attractive color and of even grain is quarried as marble. Well-known examples are the beds quarried at Knoxville, Tenn., and Carthage, Mo.

3. Travertine and "onyx marble." These forms of calcium carbonate are precipitated by lime-bearing waters. Travertine, often called calcareous tufa, is massive porous to compact limestone, found generally over the faces of limestone bluffs, also filling crevices in limestone and around springs. It does not occur in many places in sufficient quantities and of the requisite purity and color to be of service, although it has been used as an ornamental structural material, notably in the floors, stairways, and parts of the interior walls of the concourse of the Pennsylvania Railroad station in New York City, which are constructed of a gray travertine from Italy. "Onyx marble," on the other hand, is found in workable quantities in many places, such as caves and shallow rock basins where waters have been slowly evaporated. It is very finely crystalline; is generally banded, in some places delicately, in others brilliantly; and takes a high polish. Oxidized compounds of iron and manganese produce the bright bands and colored veins that are characteristic of "onyx marble." The present supply of "onyx marble" used in the United States comes principally from Lower California, southern California, and Arizona, where it has been deposited from waters issuing from hot springs.

Certain varieties of limestone are best distinguished by their chemical composition. Among these are high-calcium limestone, magnesian limestone, dolomite, argillaceous limestone, and siliceous limestone, although, of course, the distinctions between some of them are not sharp and the varieties grade insensibly into one another.

The distinguishing characteristic of high-calcium limestone is its freedom from magnesium, as well as from ingredients regarded as impurities, such as silica, alumina, the oxides and sulphides of iron, alkalies, phosphates, and organic matter. High-calcium limestone carries from 90 to more than 99 per cent of calcium carbonate and may embrace all the physical varieties of limestone except cherty rock.

Magnesian limestone contains magnesium carbonate in any quantity up to 45.65 per cent. Most magnesian limestones carry either a small or a high percentage of magnesium carbonate, although there are a few deposits that are intermediate in composition. Magnesian limestone may embrace several varieties, texturally.

Dolomite is a mineral composed of the double carbonate of calcium and magnesium. It contains 54.35 per cent CaCO_3 and 45.65 per cent

MgCO_3 .¹ In practice magnesian limestone containing 20 per cent or more of magnesium carbonate has generally been called dolomite, but it would be preferable if magnesian limestone could be distinguished as "low-magnesium" and "high-magnesium," the term "dolomite" being restricted to rock containing nearly, if not quite, the theoretical quantity of magnesium carbonate necessary to combine with the calcium carbonate in the proportions given above, or in the ratio of 1:1.19. The mineral dolomite in places forms rock masses, in which the crystals of dolomite can be distinguished. In some rocks these crystals make up a large proportion of the beds, and on weathering the rock crumbles to a sand composed of dolomite grains. The texture of magnesian limestone and dolomite is commonly granular, and hence rougher on weathered surfaces than that of high-calcium limestone. The rock is also generally more permeable than high-calcium stone.

Magnesian and dolomite marbles occur in many places and are satisfactory as building and ornamental stone, provided they are homogeneous in composition and texture. Compared with high-calcium marble dolomite marble is a little harder, withstands greater pressure, and, according to a series of tests made by Merrill² to determine the relative solubility of certain calcareous rocks used for building and ornamental work and also the manner in which the solvent acted, appears to be less readily affected by moisture laden with carbon dioxide. The ultimate aim of the experiments was to ascertain how the stones would withstand the effects of an atmosphere containing carbon dioxide, which would make the rain acid. Dolomite is likely to be more permeable to moisture than high-calcium stone, however, and if so, would dissolve more rapidly. Marble containing bands of both high-calcium and high-magnesium stone should therefore not be used for exposed work on account of its liability to differential weathering.

Argillaceous limestone contains a considerable proportion of clay material, consisting mainly of silicate of alumina. Clay material was probably introduced into the limestone during its formation on the sea bottom. Limestone of this character is not suitable for building stone, because it disintegrates too rapidly. It is used to a small extent in the manufacture of cement.

Siliceous limestone is a rock containing fine silica sand that was deposited with calcareous sediments in the sea. Other varieties of limestone contain silica in the form of chert, segregated in nodules and bands and in the form of crystalline quartz that has been introduced by mineral-bearing waters into the pores of the rock and into

¹ Dana, E. S., A textbook of mineralogy, p. 358, New York, John Wiley & Sons, 1900.

² Merrill, G. P., Report on some carbonic-acid tests on the weathering of marbles and limestones: U. S. Nat. Mus. Proc., vol. 49, pp. 347-349, 1915.

cavities, forming geodes and veins. Some limestones also contain a siliceous cement. Exceptionally, limestone may contain calcium silicate in the form of wollastonite, produced by igneous metamorphism.

DEFINITION OF MARBLE.

Marble is a term applied commercially to a granular crystalline limestone or dolomite, and even to other rocks, such as serpentine,¹ that are susceptible of polish and possess attractive colors. Scientifically, marble is a rock composed mainly of granular crystalline calcite or dolomite or of both.

METAMORPHISM.

In the formation of marble from limestone, crystallization has resulted from the effects of heat and pressure, usually aided by the action of water. The calcite or dolomite crystals in a thin section of marble are generally irregular in size, shape, and arrangement, and many of them are twinned. Crystallization has probably occurred below the surface of the earth long before the rocks were brought into their present position by crustal elevation and erosion. True marbles are therefore found in regions that have been subjected to metamorphic action, and they are associated with other metamorphic rocks, such as gneiss, schist, quartzite, and slate, and are usually situated near areas of igneous rocks, such as granite and diorite. Little chemical change takes place during the metamorphism of pure limestone and dolomite to marble, but the rock mass becomes more completely crystalline. Deposits of marble occur in the form of lenticular masses, interbedded with other metamorphosed rocks, and also in zones along the contact of a limestone with an igneous rock. If the original limestone contains silica and other impurities, certain silicate minerals may be developed in the marble.

CHEMICAL COMPOSITION.

High-calcium limestone and calcite marble contain from 90 to more than 99 per cent calcium carbonate. Pure dolomite, either nonmetamorphosed or metamorphosed, consists of approximately 54 per cent calcium carbonate and 46 per cent magnesium carbonate, but in most dolomites the percentages are slightly lower on account of the presence in the rock of foreign minerals or impurities. Marbles that are mixtures of calcite and dolomite may be of intermediate compositions. A good example of calcite marble is described on page 68. This

¹ Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, pp. 49-50, 1912. Dale describes among the commercial marbles of Vermont a serpentine and a chrome-mica schist. It is interesting to note that some of the most handsome polished samples of banded and colored marble produced recently in Alaska owe their distinctive banding to their schistose character.

marble, the white variety from Tokeen, Alaska, contained 99.51 per cent of calcium carbonate, and a dolomitic marble from Admiralty Island, Marble Cove (p. 52), contained 61.11 per cent of calcium carbonate and 39.10 per cent of magnesium carbonate. Dale¹ mentions similar examples from Vermont. A white marble quarried near Proctor, Vt., contained 98.37 per cent of calcium carbonate and a white dolomite marble quarried at Lee, Mass., contained 55.14 per cent of calcium carbonate and 43.88 per cent of magnesium carbonate. A piece of white and gray veined marble from Tokeen, Alaska (p. 69), proved to be megnesian, containing 81.90 per cent of calcium carbonate and 14.93 per cent of magnesium carbonate. A crystalline limestone of intermediate composition from Tuckahoe, N. Y., is stated by Kemp² to contain 70.1 per cent of calcium carbonate and 25.40 per cent of magnesium carbonate. Serpentine and schistose marbles vary greatly in composition from the proportions given above.

Among the common impurities in limestone and marble are varying percentages of silica, alumina, iron oxides and carbonates, iron pyrites and marcasite (iron disulphide), manganese oxides, gypsum, alkalis, and carbonaceous material, including graphite. Clay is introduced into the limestone beds while the sediments are being deposited on the sea bottom and is most commonly found along the bedding places, but it is also disseminated through the rock. Clay also results from the decomposition of impure limestone and marble in the process of weathering at the surface, in joint cracks that have been enlarged by solution, and in solution channels and caves. Surface clay is carried down into cracks, crevices, and irregularities in the rock surface, and in quarries that are operated on a large scale it is difficult to separate this clay cheaply from the associated rock. Silica is both an original and a secondary impurity in limestone. In ordinary hard limestone it occurs as nodules or masses of chert (flint) or else combined with alumina as clay matter. In marble it is usually found combined with some other mineral, such as alumina, iron, calcium, or magnesium, and occurs, therefore, in the form of silicate minerals. Alumina is commonly present in combination with silica in silicate minerals or as clay matter. Iron compounds may have been disseminated with the original sediments, but they have also been brought in by percolating waters. Chemical action between the iron compounds and the calcium carbonate and other minerals has resulted in the replacement of particles of calcite by iron compounds. Sulphur is present in iron disulphide and in gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), so that it is not free under ordinary conditions. The alkalis, soda and potash, occur in very small quantities in some limestones and marbles and in their clay impurities, probably in the form of silicates.

¹ Dale, T. N., op. cit., p. 13.

² Kemp, J. F., A handbook of rocks, 2d ed., p. 110, 1900

The impurities in marble are present chiefly as grains of definite minerals, ranging in size from those that are microscopic to those that may be readily seen by the unaided eye. Among the common mineral impurities are quartz, hematite, limonite, pyrite, marcasite, graphite, chlorite, hornblende, pyroxene, tourmaline, feldspar, biotite, muscovite, sericite, talc, epidote, tremolite, titanite, wollastonite, and diopside.

PHYSICAL PROPERTIES.

Valuable qualities possessed by most marbles are sufficient hardness, cohesiveness, and strength for the purposes to which they are most adaptable, slight translucence, moderate specific gravity, pleasing textures and colors, and susceptibility to polish. Other properties that must be considered in connection with the use of marble for certain purposes are its rift or grain, solubility, porosity, permeability, elasticity, expansiveness under heat, flexibility, deformation under pressure, thermal conductivity, and sonorousness, but some of these properties are chiefly of scientific interest.

The physical properties of marble have been described at some length in bulletins by Dale¹ and Bowles,² both of which are available for free distribution, and therefore this subject will not be discussed further here. The paper by Bowles should be in the hands of all who contemplate opening marble quarries, as well as of those who are now engaged in quarrying marble.

WEATHERING.

On the outcrop and just beneath a cover of residual clay, débris, and soil, limestones and marbles are generally disintegrated, or weathered, and stained to depths depending on the physical and chemical character of the stone and on climatic and atmospheric conditions. Impurities occur in greater proportion in the weathered rock than in the unweathered, because they are less soluble than calcium carbonate.

THE MARBLE DEPOSITS.

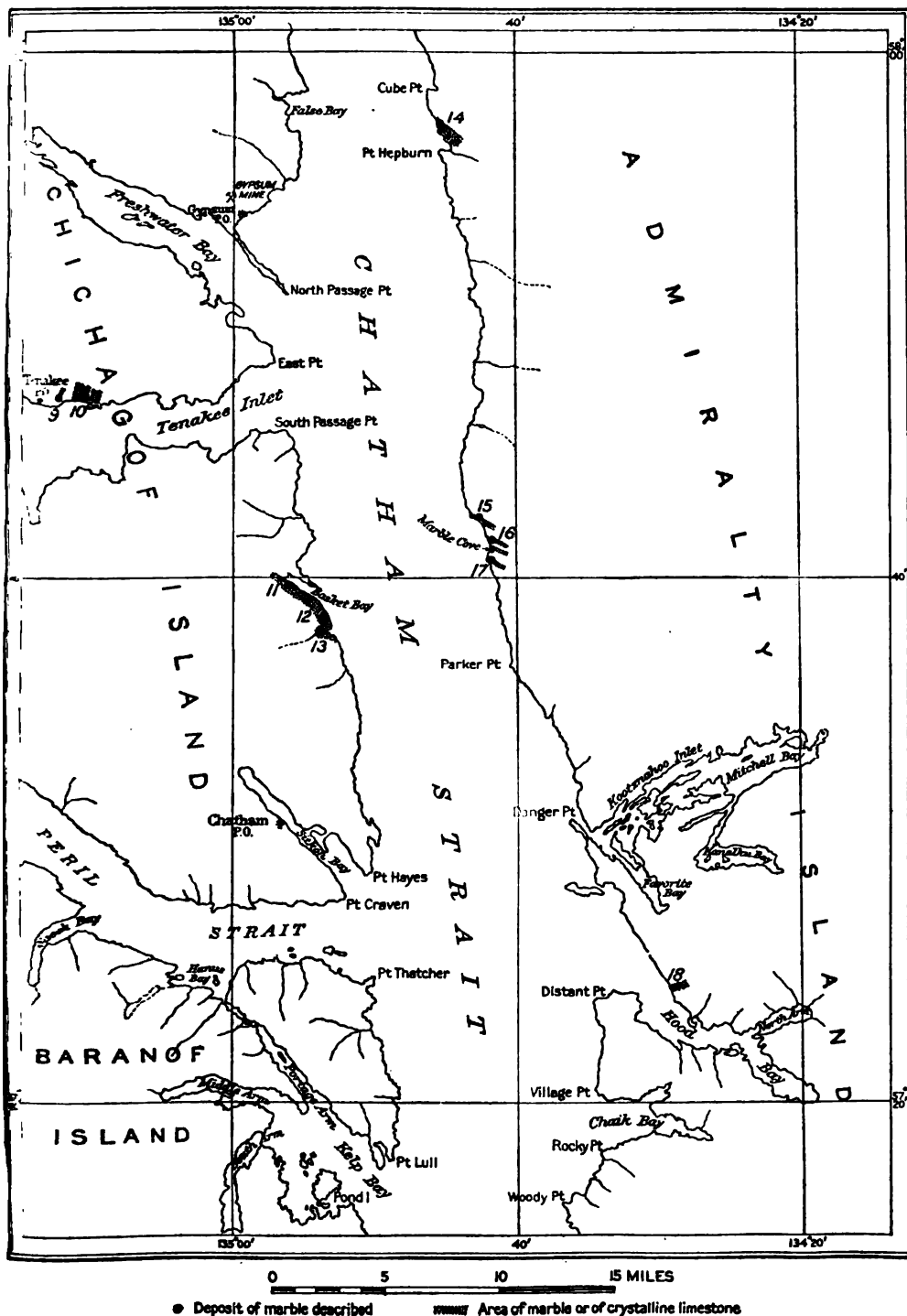
By E. F. BURCHARD.

GEOGRAPHIC DISTRIBUTION.

The mineral lands of southeastern Alaska lie in the Juneau, Skagway, Sitka, Wrangell, and Ketchikan mining districts, the outlines of which are shown on the index map (Pl. I). Deposits of marble have been found in all these districts. On some of them claims have been filed and prospecting has been done, according to regulations, and on some sufficient development work has been done

¹ Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, 170 pp., 1912.

² Bowles, Oliver, The technology of marble quarrying: Bur. Mines Bull. 106, 174 pp., 1916.



MAP SHOWING MARBLE DEPOSITS EXAMINED ON CHICHAGOF AND ADMIRALTY ISLANDS.

From Coast and Geodetic Survey chart No. 8306.

to warrant the issue of patents; but on some of the deposits described herein no claims have yet been filed, and on others little or nothing has been done besides filing claims. In the Juneau district deposits of marble have been noted on the mainland and on Admiralty Island; in the Skagway district marble occurs on the mainland on the east side of Glacier Bay and on several small islands in the bay; in the Sitka district marble forms some of the shore line of the southeastern part of Chichagof Island; in the Wrangell district the marble occurs chiefly on the mainland east of Wrangell Island, but a little has been noted on Kupreanof Island; in the Ketchikan district marble is widespread and abundant, having been found in both the northern and southern parts of Prince of Wales Island and on Kosciusko, Marble, Orr, Heceta, Dall, Long, and Revillagigedo islands. The relations of all these localities are shown on the index map (Pl. I) and Plates II to V and figures 1 and 4 show on a larger scale the geography of the several marble-bearing localities. Such geologic maps of this region as have been published are mainly of a reconnaissance nature and are included in Survey Bulletins 287 and 347. The maps showing the geography of the region in greatest detail are the charts issued by the Coast and Geodetic Survey, Department of Commerce, and these maps served as bases for Plates II to V and figures 1 and 4. The principal Coast and Geodetic Survey charts covering the areas containing the marble deposits of southeastern Alaska are as follows:

- 8100. Revillagigedo Island and southeastern part of Prince of Wales Island.
- 8150. Western part of Prince of Wales Island, Kosciusko, Marble, Orr, Heceta, Dall, and Long islands.
- 8200. Northern part of Prince of Wales Island, Kupreanof Island, Wrangell Island, and mainland to the east.
- 8250. Eastern part of Chichagof Island and western part of Admiralty Island.
- 8300. Mainland on Stephens Passage.
- 8306. Glacier Bay.

These charts, with the exception of No. 8306, which is on a scale of 1:160,000, or about 0.39 inch to 1 statute mile, are on a scale of 1:200,000, or approximately 0.32 inch to the statute mile.

TOPOGRAPHIC RELATIONS.

The mainland and islands of southeastern Alaska are generally mountainous, and there is little level land either as upland area or along the shores. (See Pls. I-V and figs. 1 and 4.) Along much of the coast line the hills and mountains rise abruptly and the dense forest growth, extending down to the level of high tide, overhangs the steep banks. The islands are separated by an intricate system of waterways and fiords, known locally as straits, canals, channels, passages, sounds, narrows, inlets, bays, coves, and arms, some of which reach far inland. Many of these waterways are very deep and can

be safely navigated by the largest ocean steamers, but some are so shallow as to be navigable only at high tide by boats of moderate draft. The coast and entrances to harbors are rocky, and in places the greatest care is necessary in navigation in order to avoid rocks that are barely submerged. The topography is so rough that only in favored localities or at great expense can wagon or tram roads be constructed. The waterways are therefore of great value in affording routes of communication between different portions of the region and between this region and the Pacific coast ports of the United States. Indeed, were it not for water transportation the mining and quarrying industries in southeastern Alaska could scarcely have been developed.

Some of the deposits of marble are situated on the shores of sheltered bays that are deep enough to afford anchorage or wharfage for ocean-going freight vessels. Others, however, are on rocky, exposed portions of the coast, and still others are a mile or more from the shore and at considerable altitudes. Naturally the deposits most convenient of access will be developed first. Freight rates have been much reduced in the last few years through competition and are reported at present to be moderate.

The rock surface is in general thickly overgrown with small to medium-sized timber and dense underbrush and has a soil cover of decayed wood, moss, and mold, from a few inches to 3 or 4 feet thick as a rule, but thicker in hollows and crevices in the rock. The timber consists of hemlock, spruce, and cedar, which have in few places a maximum diameter of more than 4 feet. At the north, in the vicinity of Glacier Bay, the timber is much smaller, but the underbrush is dense.

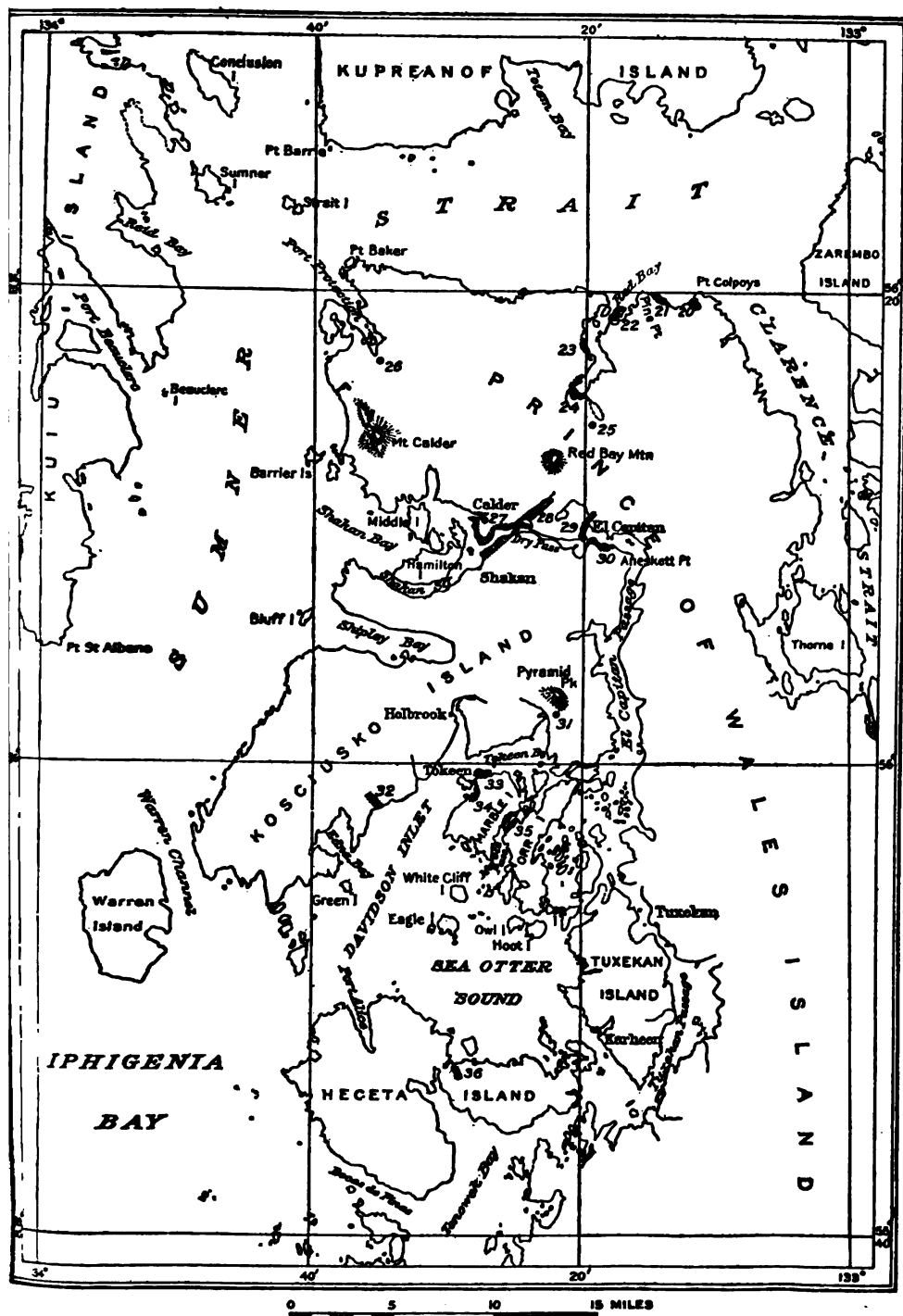
The following paragraph, by Wright,¹ on the growth of vegetation is of interest here:

The luxuriant growth of vegetation along the coast of southeastern Alaska may well be compared with that of a tropical region. This is caused by the moist and temperate climate and the long summer days at this high altitude. At elevations below 1,500 feet bushes, ferns, and tall grasses grow profusely, especially in the valleys and gulches. These form in places a dense and almost impassable undergrowth and are a great hindrance to the prospector. Among the most common of these shrubs are the thorny devil's club, the salmonberry, the elderberry, the huckleberry, the high-bush cranberry, various willows, the black alder, and the white alder, the latter forming thickets along the streams and mud flats.

GEOLOGIC RELATIONS.

Most of the marble beds in southeastern Alaska appear to be portions of extensive belts of limestone that have been metamorphosed by an intrusive mass of granodiorite at or near the contact,

¹ Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, p. 31, 1908.



• Deposit of marble described Area of marble or of crystalline limestone

MAP SHOWING MARBLE DEPOSITS EXAMINED ON NORTHERN PRINCE OF WALES ISLAND AND ON KOSCIUSKO, MARBLE, ORR, AND HECETA ISLANDS.

From Coast and Geodetic Survey charts Nos. 8200 and 8150.

or by the general metamorphism of the region, or by a combination of the two agencies. The relations of the belts of sedimentary and intrusive rocks are shown in Plate I. Both the limestone and the marble are cut in many places by thin dikes, principally of basalt, andesite, dacite, and diabase, all more or less altered and containing secondary calcite, and in places the marble beds are interstratified with graywackes, schists, and lavas. Both the limestone and the marble beds are generally much fractured and jointed, the marble in places showing joints that are open to considerable depths. The limestone beds associated with the marble deposits are of Paleozoic age and at a few places, notably in and near the northern part of Prince of Wales Island, have yielded fossils that are regarded as Silurian.

TYPES OF MARBLE AVAILABLE.

Many types of marble are available in southeastern Alaska. Probably the most common and the one which thus far has been exploited commercially on the largest scale is a fine to medium grained crystalline white to bluish-gray marble with gray to dark-bluish veins, bands, and clouded areas. Other crystalline and schistose marbles that give promise of being developed successfully show handsome contrasting "verde antique" effects and other striking combinations of color, such as green and pink, black and white, and white and yellow. The green color appears to be due to chloritic material and possibly to epidote, the bluish and black veins possibly to graphite, and the pink and yellow shades to iron oxide. Certain marble deposits give promise of affording statuary material. Some dense non-crystalline limestones have attractive colors of pink and chocolate mottled, gray, blue, and black, and are susceptible of receiving a high polish.

The tabular classification or index of the principal varieties of marble in southeastern Alaska according to color given on pages 31-39 has been prepared to furnish the reader a condensed and systematic description of the marbles available and to enable him to find quickly the detailed description of any marble together with the notes concerning the locality in which it occurs.

In this classification the following varieties of marble are distinguished:

White; nearly white; cream-colored; white with gray veins (in part banded); white with dark-gray to black veins or bands; white with blue veins or bands; white with yellow veins or clouds; gray (in part veined and banded); bluish gray (some banded with white); pearl-gray; light blue; black (blue-black); green and banded with green; pink (also pink and white); yellow; mottled, chiefly red and white, red and gray, brown and white; variegated colors; schistose (varicolored bands).

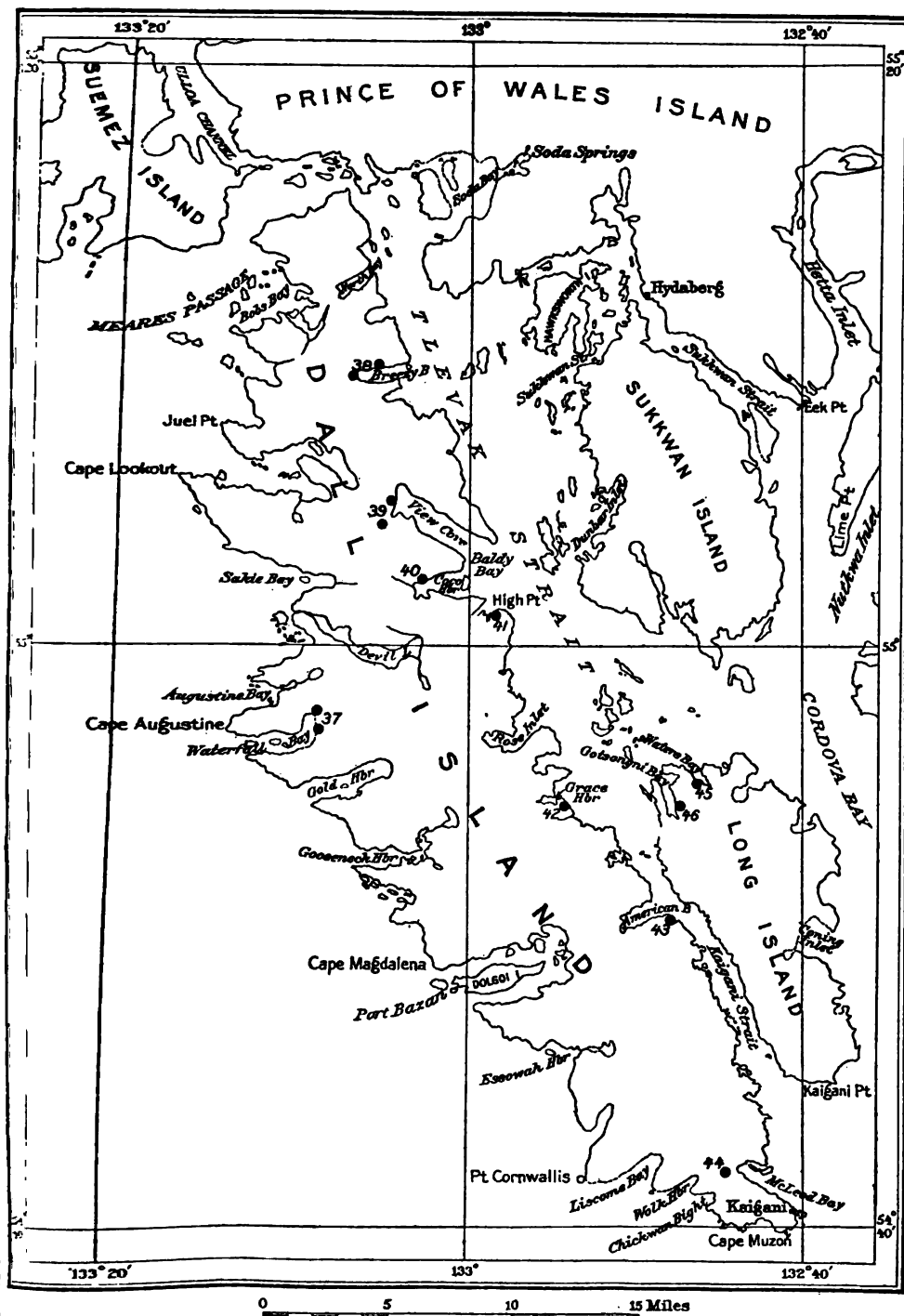
The terms "fine," "medium," and "coarse," describing the grain or grade of texture of the marbles, are here used according to a definite scale of average grain diameters. A marble is described as having a fine grain if its average grain diameter is 0.10 millimeter or less. A marble whose grain is just visible to the average unaided eye or is still finer would thus fall within the fine grade. A medium grain is one that averages from 0.11 to and including 0.50 millimeter, and a coarse grain is one that averages larger than 0.50 millimeter. A classification of Vermont marbles into six grades of texture was devised by Dale¹ but was found to be not adaptable to the wide range in texture displayed by Alaska marbles. The relation between the present classification and the Vermont marble classification is shown in the following outline:

Relation between grades of texture of Alaskan and Vermont marbles.

Name.	Alaska grade. (Average grain diameter in hundredths of a millimeter.)	Vermont grade.
Fine.....	10 or less.....	{01. Finer than "extra fine." 1. Extra fine. 2. Very fine.
Medium.....	11 to 50.....	{3. Fine. 4. Medium 5. Coarse.
Coarse.....	51 or more.....	{6. Extra coarse. 7. Do. 8. Do.

The classification in detail is set forth on the following pages.

¹ Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, p. 54, 1912.



MAP SHOWING MARBLE DEPOSITS EXAMINED ON DALL AND LONG ISLANDS.

From Coast and Geodetic Survey chart No. 8150.

THE MARBLE DEPOSITS.

31

Classification of Alaska marbles.

White.

Locality.	Texture.	Average grain diameter, in hundredths of a millimeter.	Vermont grade.	Grain form.	Petrographic name.	Development.	No. on map (Pl. I).	Described on pages—
South Marble Island, Glacier Bay	Medium	20	4-5	Uneven	Calcite marble	None	7	44
Chichagof Island, Basket Bay	Fine	10	2	Even, elongate	Magnesian calcite marble	do	11	46-47
Chichagof Island, cove south of Basket Bay	do	8	2	Even	Calcite marble	do	13	48
Admiralty Island, Marble Cove	do	40	5-6	do	do	do	17	52
Admiralty Island, one-third mile south of Marble Cove	Medium	40	5-6	Uneven	Calcite marble, with dusty inclusion of carbonaceous (?) material	do	17	52-53
Admiralty Island, Hood Bay	Fine	0	2	Even	Calcite marble	do	18	54-55
Prince of Wales Island, Shakan Bay (Calder)	Medium	15	4	Uneven	do	Quarry	27	60-62
Prince of Wales Island, Dry Pass	Coarse	124	3	Even	do	None	28	62-63
Prince of Wales Island, El Captain	Medium	12-15	3	Uneven	do	Prospect	29	63-64
Marble Island, Tokeen	do	31	5	do	do	Quarry	33	68, 70
Marble Island, 1½ miles southwest of Tokeen	do	5	01	Even	do	Prospect	34	72-73
Dall Island, Waterfall Bay	Fine	6	1	do	Calcite marble, with a little sericite	do	37	77-80
Dall Island, Coco Harbor	do	13	4	do	Calcite marble	None	40	82
Long Island, Waters Bay	Medium	25	5	do	do	Prospect	45	83-84
Long Island, Gotsongni Bay	do	25	5	Uneven	do	do	46	84-85
Prince of Wales Island, Dolomite	Fine	10	2	Even	Calcite marble, with a little alumina, silica, and pyrite. Dolomite marble	A abandoned quarry	47, 48	85-86
Ryvilagtedo Island, Carroll Inlet	do	10	2	Even	Dolomite marble	Prospect	58	97

Classification of Alaska marbles—Continued.

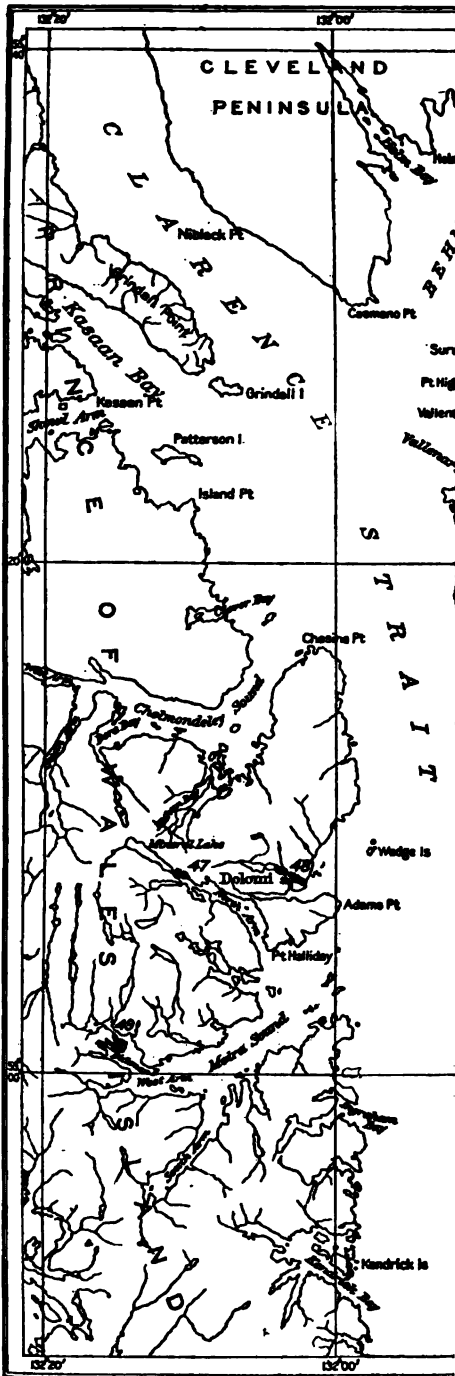
Nearly white.

Locality.	Texture.	Average grain diameter, in hundredths of a millimeter.	Vermont grade.	Grain form.	Petrographic name.	Development.	No. on map (Pl. I).	Described on pages—
Limestone Inlet, Mainland.	Medium.	26	5	Irregular.	Calcite marble.	Prospect.	1	40
Willoughby Island, Glacier Bay.	Medium to coarse.			Uneven.	do.	None.	8	44-45
Chichago Island, Tenakee Inlet.	Coarse.	4	01	Even.	Calcite marble, in part schistose.	do.	9	45
Do.	Fine.				rite, feldspar, quartz, and chlorite.	do.	10	45-46
Do.	Fine groundmass with coarse crystals.	7-89	1-7	Uneven.	Calcite marble with curved twinned brecciated plates.	do.	10	45-46
Chichago Island, Basket Bay.	Fine.	9	2	Even, elongate.	Magnesian calcite marble.	do.	11	46-47
Prince of Wales Island, Point Colpoys.	do.			Even.	Calcite marble.	Prospect.	20	56-57
Prince of Wales Island, head of Port Protection.	do.			Uneven.	Limestone, partly metamorphosed.	None.	26	59
Kodiako Island, opposite El Capitan.	do.			do.	Calcite marble cut by thin seams of quartz.	Prospect.	30	64-65
Marble Island, Orr Inlet.	Medium to coarse.			do.	Calcite marble.	do.	35	74
Dall Island, Baldy Bay.	Medium.			do.	Calcite marble with a few grains of pyrite.	None.	41	82
Dall Island, Grace Harbor.	Fine.			Even.	Calcite marble.	do.	42	82
Prince of Wales Island, Dickman Bay.	do.	10	2	Uneven.	do.	Prospect.	49	86-90
Eastern Passage, near Lake Virginia.	Coarse.			do.	Thalose calcite marble.	None.	60	91-92
Blake Channel.	Medium.			do.	Calcite marble.	Prospect.	61	92-93
Ham Island.	Coarse.	139-394	8	do.	do.	Prospect.	92	93-96
Revilagiedo Island, George Inlet.	Fine to medium.			do.	Schistose calcite marble.	None.	55, 56, 57	96-97

Cream colored.

Mainland, Glacier Bay, south of Sandy Cove.	Fine.			Uneven.	Calcite marble.	None.	3	41
Willoughby Island, Glacier Bay.	Medium.	46	6	do.	Calcite marble, cherty in places.	do.	8	44-45
Prince of Wales Island, west side of Red Bay.	Fine.			do.	Calcite marble.	Prospect.	23	57-58

U. S. GEOLOGICAL SURVEY



• Deposit of marble •

MAP SHOWING MARBLE DEPOSITS EXAMINED

From Coast

White with gray veins (in part banded).

South Marble Island, Glacier Bay.....	Medium.....	20	4-5	Even.....	Calcite marble.....	None.....	7	44
Admiralty Island, one-third mile north of Marble Cove.....	do.....	36	5-6	Slightly uneven.....	do.....	do.....	15	50-52
Do.....	do.....	5-29	1-5	Uneven, banded ..	Calcite marble with mica, tremolite, and possibly pyrite and graphite.....	do.....	17	52-53
Prince of Wales Island, head of Red Bay.....	do.....	20	5	Uneven.....	Calcite marble.....	Drill prospect.....	24	58-59
Prince of Wales Island, El Capitan.....	do.....	15	4	do.....	do.....	Quarry.....	29	63-64
Kachuko Island, head of Token Bay.....	do.....	13	3	Very uneven.....	do.....	Prospect.....	31	65
Marble Island, Token.....	do.....	13	3	Very uneven.....	Magnesian calcite marble.....	Quarry.....	33	68-69

White with dark-gray to black veins or bands.

Marble Island, Token.....	Medium.....	13	3	Very uneven.....	Magnesian calcite marble.....	Quarry.....	33	68-69
Orr Island.....	Fine to coarse.....	10-89	2-3	Uneven.....	Calcite marble, with a little magnesia and silica.....	do.....	35	74-76
Dall Island, View Cove.....	Medium.....	12	3	do.....	Calcite marble.....	None.....	39	80-81
Long Island, Waters Bay.....	do.....	12	3	do.....	Calcite marble with graphitic bands.....	Prospect.....	45	83-84

White with blue veins or bands.

Prince of Wales Island, Shaskan Bay (Calder).....	Fine.....	12	3	Uneven.....	Calcite marble.....	Quarry.....	27	60-62
Long Island, Waters Bay.....	Medium.....	13	3	do.....	Calcite marble with graphitic bands.....	Prospect.....	45	83-84
Prince of Wales Island, Dickman Bay.....	do.....	13	3	do.....	do.....	do.....	49	86-90

White with yellow veins or clouds.

Dall Island, Waterfall Bay.....	Fine.....	10	2	Even.....	Calcite marble.....	Prospect.....	37	77-80
Dall Island, Grace Harbor.....	do.....	10	2	(?).....	do.....	None.....	42	82
Prince of Wales Island, Dickman Bay.....	do.....	10	2	Uneven.....	Calcite marble.....	Prospect.....	49	86-90

Classification of Alaska marbles—Continued.

Gray (in part veined and banded).

Locality.	Texture.	Average grain diameter, in hundredths of a millimeter.	Vermont grade.	Grain form.	Petrographic name.	Development.	No. on map (Pl. I).	Described on pages—
Mainland, Limestone Inlet.....	Medium.....	26	5	Uneven.....	Calcite marble.....	Prospect.....	1	40
Mainland, Glacier Bay, Sandy Cove.....	do.....			Irregular.....	Calcite marble, slightly magnesian in places.....	None.....	2	41
Mainland, Glacier Bay, south of Sandy Cove.....	Fine.....			Uneven.....	Nonmetamorphosed limestone.....	Prospect.....	3, 4	41, 43
North Marble Island, Glacier Bay.....	Medium.....	25	5	do.....	Calcite marble.....	None.....	6	43-44
Willoughby Island, Glacier Bay.....	do.....	46	6	do.....	Partly metamorphosed limestones in places.....	do.....	8	44-45
Chichagof Island, Tenakee Inlet.....	Fine.....			do.....	Calcite marble, pyritiferous in places.....	do.....	10	45-46
Chichagof Island, Basket Bay.....	do.....			do.....	Graphitic magnesian calcite marble.....	do.....	11	46-47
Prince of Wales Island, 2 miles west of Point Colpoys.....	do.....	7	01	Even.....	Limestone, slightly metamorphosed in places.....	Prospect.....	21	57
Prince of Wales Island, west shore of Red Bay.....	do.....	5	01-1	Uneven.....	Calcite marble.....	do.....	23	57-58
Prince of Wales Island, head of Port Protection.....	do.....			do.....	Limestone, partly metamorphosed in places.....	None.....	26	59
Prince of Wales Island, Dry Pass.....	Coarse.....	84	7	do.....	Calcite marble.....	do.....	28	62-63
Kodiak Island, opposite El Capitan.....	Fine.....			do.....	Calcite marble cut by thin seams of quartz.....	Prospect.....	36	76-77
Dall Island, Waterfall Bay.....	do.....	4	01	do.....	Calcite marble.....	do.....	37	77-80
Dall Island, Breezy Bay.....	do.....			do.....	do.....	None.....	38	80
Dall Island, View Cove.....	Medium.....			Uneven.....	do.....	do.....	39	80-81
Long Island, Waters Bay.....	do.....			Even.....	do.....	Prospect.....	45	83-84
Prince of Wales Island, Dickman Bay.....	Fine.....			Uneven.....	do.....	do.....	49	86-90
Mainland, Eastern Passage, near Lake Virgine.....	Medium.....	14	4	Even.....	do.....	None.....	50	91-92
Blake Channel.....	do.....			do.....	Calcite marble with graphitic (?) streaks.....	Prospect.....	51	92-93
Hain Island.....	Coarse.....	28	5	Uneven.....	Calcite marble.....	do.....	52	93-95
Revillagigedo Island, George Inlet.....	Fine to medium.....			do.....	Schistose marble.....	None.....	55, 56, 57	96-97

Bluish-gray (some banded with white).

Michigof Island, cove south of Basket Bay	Fine	8	1-2	Even	Calcite marble with minute grains of limonite and pyrite.	None	12	47-48
Kupreanof Island, Duncan Canal	Fine to coarse			Uneven	Calcite marble with streaks and patches of white calcite.	do.	19	56
Prince of Wales Island, west shore of Red Bay	Fine	5	1	do.	Calcite marble.	Prospect	23	57-58
Prince of Wales Island, Dry Pass, near Winter Harbor	Coarse	84	7	do.	do.	None	28	62-63
Koedusko Island, head of Toheen Bay	Fine	4	01	do.	do.	Prospect	31	65
Marble Island, Orr Inlet	do.			do.	Calcite marble with streaks of graphite.	do.	35	74-76
Dall Island, Baldy Bay	Medium			do.	Calcite marble with a few grains of pyrite.	None	41	82
Long Island, Gotsongni Bay	do.			Even	Calcite marble.	do.	48	84-85
Mainland, Eastern Passage, near Lake Virgula	Fine			do.	do.	do.	50	91-92
Mainland, Blake Channel	Medium	28	5	Uneven	Calcite marble with graphitic (?) streaks.	Prospect	51	92-93
Ham Island	do.	32	5	Uneven, elongate	Calcite marble with a little graphite	do.	52	93-95

Pearl gray.

Dall Island, View Cove	Fine	8	2	Nearly even	Calcite marble.	None	39	80-81
Long Island, Waters Bay	Medium	About 23	5	Even	do.	Prospect	45	83-84

Light blue.

Prince of Wales Island, Shakan Bay (Ukder)	Fine			Uneven	Calcite marble.	Quarry	27	60-62
Prince of Wales Island, El Capitlan	Medium			do.	do.	Prospect	29	63-64

*Classification of Alaska marbles—Continued.***Dark blue.**

Locality.	Texture.	Average grain diameter, in hundredths of a millimeter.	Vermont grade.	Grain form.	Petrographic name.	Development.	No. on map (Pl. I).	Described on page—
Chichagof Island, Basket Bay.....	Fine.....			Uneven.....	Magnesian calcitic marble with streaks of calcite.	None.....	11	46-47

Blue and white clouded.

Long Island, Gotsongul Bay.....	Medium.....	20	4	Even.....	Calcite marble.....	None.....	46	84-85
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Blue and white speckled.

Admiralty Island, one-half mile south of Marble Cove.	Medium.....	35	5-6	Uneven.....	Twinned dolomite and twinned calcite with segregations of olivine altered to serpentine and magnetite. Carbonaceous matter and sulphides also present.	None.....	17	53-54
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Black (blue black).

Marble Island, Tokcen.....	Fine.....	5	1	Uneven.....	Limestone with carbonaceous and pyrite specks.	Quarry.....	33	67-68
Dall Island, Waterfall Bay.....	do.....	About 3	01	do.....	Calcite marble.....	Prospect.....	37	77-80
Dall Island, View Cove.....	do.....			do.....	Limestone, partly metamorphosed, probably graphitic.	do.....	39	80-81
Prince of Wales Island, Dickman Bay.....						Quarry.....	49	86-90

THE MARBLE DEPOSITS.

37

Green and banded with green.

Mainland, Limestone Inlet.....	Medium.....	18	4-5 Medium.....	Slightly irregular.....	Calcite marble.....	Prospect.....	1	40
Mainland, east of Sandy Cove, Glacier Bay.....	Fine.....			Uneven.....	Partly metamorphosed limestone.....	None.....	6	43
Chichagof Island, Tenakee Inlet.....	Coarse.....			.....do.....	Calcitic schistose marble.....	Prospect.....	9	45
Admiralty Island, near Point Hepburn.....	Fine to coarse.....			Very irregular.....	Calcitic schistose marble carrying quartz, feldspar, epidote, hornblende, and pyrite.....	None.....	14	49-50
Koonuk Island, near Holbrook.....	Fine.....			Uneven.....	Limestone breccia.....	Prospect.....		65-66
Marble Island, 1½ miles southwest of Tokten.....	Fine to medium.....	3-24	01-5	Very uneven.....	Pyritiferous calcite marble with silicate minerals.....	.....do.....	34	72-73
Dall Island, View Cove.....	Fine.....	4	1	Even.....	Calcite marble with streaks of micaceous and carbonaceous material.....	None.....	30	80-81
Prince of Wales Island, Dickman Bay.....	Coarse.....	75	6	Uneven.....	Calcite marble with bands containing quartz, epidote, plagioclase, and chlorite.....	Prospect.....	49	86-90
Do.....	Fine.....	About 5	01	.....do.....	Calcite with grains of quartz, dolomite, plagioclase, chlorite, biotite, and epidote.....	.....do.....	49	86-90

Pink (also pink and white).

Dall Island, Waterfall Bay.....	Fine.....	5	1	Even.....	Calcite marble.....	Prospect.....	37	77-79
Long Island, Gotsongul Bay.....	Medium to coarse.....			Uneven.....	.....do.....	.....do.....	46	84-85

Yellow (generally yellow only in part).

[See also "Mottled."]

Koonuk Island, 3 to 4 miles northeast of Edna Bay.....	Fine.....			Uneven.....	Limestone stained with iron oxide.....	Prospect.....	32	66
Dall Island, View Cove.....	.....do.....	4	1	Even.....	Calcite marble.....	None.....	39	80-81
Long Island, Waters Bay.....	Medium.....	25	6	Uneven.....	.....do.....	.....do.....	45	83-84

Classification of Alaska marbles—Continued.
 Mottled (chiefly red and white, red and gray, brown and white).

Locality.	Colors.	Texture.	Average grain diameter, in hundredths of a millimeter.	Vermont grade.	Grain form.	Petrographic name.	Development.	No. on map (Pl. I).	Described on pages—
Mainland, south of Sandy Cove, Glacier Bay.	Chocolate-colored, pink, grayish green, and drab.	Fine.	2-7	01-1	Uneven.	Calcite marble colored by hematite and other iron oxides.	Prospect.	3	41-43
Chichagof Island, Tenakee Inlet.	Green, pink, and gray.	do.			do.	Calcite marble with pyrite specks.	None.	10	45-46
Prince of Wales Island, Point Colpoys.	Gray, red, and white.	do.			Even.	Calcite marble.	Prospect.	20	56-57
Bellis Island, Red Bay.	Gray, blue, white, and pink.	do.			do.	Limestone, slightly metamorphosed in places.	do.	22	57
Prince of Wales Island, head of Red Bay.	Light gray, cream-colored, and blue.	do.			Uneven.	Limestone, partly metamorphosed.	None.	24	59-59
Kocchuksko Island, 3 to 4 miles northeast of Edna Bay.	Red, white, and yellow.	do.			Even.	Limestone, stained with iron oxide.	Prospect.	32	65
Kocchuksko Island, near Holbrook Marble Island.	Dark and light green, and pink.	do.			Uneven.	Limestone breccia.	do.		65-66
	Bluish gray, pink, and green.	Fine to medium.	3-23	01-5	Very uneven.	Siliceous calcitic marble.	do.	34	72-73
Orr Island.	Cream-colored, brownish gray, and bluish white.	Medium.	25	5	Uneven.	Calcite marble with a little magnesia and silica.	Quarry.	35	74-76
Hecla Island.	Pink, red, chocolate-colored, green, yellow, and white.	Fine.			do.	Limestone with silica, iron oxide, and a little magnesia.	Prospect.	36	76-77
Dall Island, Waterfall Bay.	White and pink.	do.	5	1	Even.	Calcite marble.	do.	37	77-80
Do.	Black and white.	do.	5	1	do.	Calcite marble with graphite.	do.	37	77-80
Do.	Bluish gray and black.	do.	6	1	do.	Calcite marble with graphitic veins and areas.	do.	37	77-80
Dall Island, View Cove.	Black and gray.	do.	4	1	do.	Calcite marble.	None.	39	80-81
Long Island, Waters Bay.	Blue, white, and yellow.	Medium.	25	6	Uneven.	do.	do.	45	83-84
Prince of Wales Island, Dickman Bay.	Green, white, pink, and black.	Fine.			do.	Calcite, chloritic material, quartz, and hematite.	Prospect.	49	86-90

Variegated colors.

Mainland, south of Sandy Cove, Glacier Bay, 2 miles	Gray, bluish, cream-colored, yellow, reddish, chocolate colored, pink, green, and drab	Fine.....	2-7	01-1	Uneven..	Calcite colored by hematite stains.	Prospect..	3	41-43
Prince of Wales Island, 2 miles west of Point Colvig, 3 to 4 miles northwest of Edna Bay.	Yellow, stenna, and red.	.....do.....	.....	.....	Even.....	Limestone slightly metamor- phosed in places.	.....do.....	21	57
Koonak Island.....	Light and dark green, bluish, gray, pink, and brownish	.....do.....	.....	.....	.....do.....	Calcite marble.	.....do.....	32	65
Hecla Island.....	Pink, red, chocolate-colored, green, yellow, and white	Fine.....	3-23	01-5	Very un- even.	Cherty (?) calcite marble.	.....do.....	34	72-73
Dall Island, Waterfall Bay.....	Pink and white with irregular green bands.	.....do.....	5	1	.....do.....	Limestone with silica, iron ox- ide, and a little magnesia.	.....do.....	36	75-77
Dall Island, View Cove.....	Yellow with green stripes.....	.....do.....	.....	.....	.....do.....	Calcite marble with green bands of quartz, sericite, and chlorite.	.....do.....	.....	78-79
Prince of Wales Island, Dickman Bay.	Gray, white, yellow, green, black, and pink.	Fine to coarse.....	4	1	Even.....	Calcite marble.	None.....	39	80-81
					Uneven.....	Calcite, quartz, mica, chloritic material, and hematite.	Prospect..	49	80-90

Schistose (varicolored bands).

Mainland, Limestone Inlet.....	Gray, white, and grayish green	Medium.....	.....	.....	Uneven..	Calcite marble with bands of hornblende mica schist.	None.....	1	40
Chichagof Island, Tenakee Inlet..	White, green, and gray	Coarse.....	.....	.....	.....do.....	Calcite marble with mica schist	Prospects..	9	45
Admiralty Island, Point Heppburn	White, gray, green, and black..	Medium.....	19	3-4	.....do.....	Calcite marble with grains of quartz, feldspar, chlorite, and mica in bands.	None.....	14	49-50
Admiralty Island, 1 to 2 miles north of Marble Cove.	Gray, white, pink, and green..	.....do.....	15-38	4-5	.....do.....	Calcite marble with pyroxene, epidote, tremolite, quartz, pyrite, and titanite.	.....do.....	15, 16	50-52
Dall Island, American Bay.....	White, pink, and green.....	Fine to coarse.....	.....	.....	.....do.....	Micaeous calcite marble.	.....do.....	43	82-83
Dall Island, near McLeod Bay....	White, green, yellow, gray, and black.	Medium.....	.....	.....	.....do.....	Bands of calcite marble.	.....do.....	44	83
Prince of Wales Island, Dickman Bay.		Fine to coarse.....	.....	.....	.....do.....	Calcite marble, with quartz, plagioclase, chloritic mate- rial, muscovite, epidote, hio- tite, graphite, and hematite.	Prospects..	49	86-90

THE DEPOSITS.¹**MAINLAND AT LIMESTONE INLET.**

The deposits of marble in the vicinity of Limestone Inlet are on the mainland about 26 miles south-southeast of Juneau and $2\frac{1}{2}$ miles inland from the mouth of the inlet, or 1 to $1\frac{1}{2}$ miles from deep water (No. 1). Outcrops on the north bank of Limestone Creek consist of medium-grained grayish-white marble, banded in places with dark-gray streaks and veins of white calcite of coarser texture. Portions of the beds have a grayish-green color, possibly due to surface stains. Some parts of the mass are schistose and carry hornblende, mica, pyrite, and thin seams of quartz. The gray and green varieties are both susceptible of a fair polish. The surface of the marble is cut by two or more sets of joints into blocks from a few inches to 3 feet thick. The strike of the rocks is apparently between N. 25° W. and N. 30° W., and the dip is steep toward the northeast.

Two samples of marble from Limestone Inlet were examined microscopically by T. N. Dale. A specimen of the grayish-white variety showed a grain diameter of 0.037 to 1.28 millimeters, mostly 0.185 to 0.74 millimeter, with an estimated average of 0.277 millimeter. By use of the Rosiwal method the average diameter of the grains was found to be 0.0103 inch, or 0.262 millimeter. The grade is therefore medium; but, compared with Vermont marbles, according to Dale's classification, this marble would fall into grade 5 (coarse). The texture is uneven, and some pyrite was noted.

A specimen of the greenish variety showed a grain diameter of 0.074 to 0.925 millimeter, mostly 0.185 to 0.555 millimeter, with an estimated average of 0.216 millimeter. The Rosiwal measurement gave an average of 0.007 inch, or 0.1778 millimeter, thus indicating a medium texture. The grain form appears a little uneven. Very little pyrite is present in the section, and quartz is rare, in minute particles.

Associated with the schistose marble are beds of hornblende mica schist. A thin section examined by J. B. Mertie showed quartz, sericite, hornblende, chlorite, epidote (derived in large part from hornblende), and sulphides.

Two groups of marble claims have been located on this deposit, and two small prospect openings about 200 feet apart have been made near the creek bank. Between these two openings several natural exposures in the bank of the creek indicate the presence of schistose marble.

Most of the marble deposit is covered by forest growth, and little could be ascertained as to its extent or structure beyond the indica-

¹ In the descriptions of deposits the numbers in parentheses refer to corresponding numbers on the index map (Pl. I) and on other maps (Pls. II to V, figs. 1 and 4).

tions afforded by the few exposures. In order to develop this deposit a tramway must be built from the property down the creek to deep water in Limestone Inlet, a distance of about $1\frac{1}{2}$ miles. The construction of the tramway would involve the cutting away of some rocky points and the building of half a mile or more of trestle.

MAINLAND AND ISLANDS, GLACIER BAY.

Limestone and marble deposits crop out on the mainland on the east shore of Glacier Bay in the vicinity of Sandy Cove. Along the north shore of Sandy Cove (No. 2) marble is exposed for 600 feet or more, and the deposit extends back into a low ridge 50 to 75 feet above the water. This marble is hard, of a light-grayish color, and generally of medium grain, but contains many small bodies of calcite of varying size. Nearly obliterated traces of fossil brachiopods were noted in it. The marble is brecciated in places and has been disturbed by the intrusion of dikes. Some of the brecciated portions contain magnesium carbonate. The beds here are 3 feet or more in thickness, strike northward, and dip about 40° W. Where exposed the material is so much jointed and fractured that little stone of commercial size is obtainable.

On the east shore of the cove next south of Sandy Cove (No. 3) are beds of variegated marble and partly metamorphosed limestone. The colors include gray with bluish veins, cream-colored with yellow veins, reddish, mottled chocolate-colored and pink, and mottled grayish-green and drab. The rock is fine grained, hard, and brittle and takes a good polish. It is generally much fractured at the surface, especially the gray limestone. Traces of stylolites or suture joints were observed in the gray marble. The beds strike about S. 50° E. and dip steeply toward the northeast. This belt of rocks is about 500 feet thick and extends an indefinite distance south-eastward into the mountains. The bedding is variable, but for the most part the rock is fairly massive. Dikes of diabase cut the beds in east and northeast directions, and the jointing runs generally in the same directions. The ridge which the marble forms is about 50 feet high at its northwest end, where a low cliff has been cut by the stream that flows into the cove, but toward the southeast the ridge rises to 500 feet or more in height within a quarter of a mile. (See fig. 1.)

A thin section of the mottled marble was examined by T. N. Dale and G. F. Loughlin. It consists of finely granular faintly pinkish rock and coarse transparent rock in irregular alternations and inclusions. The granular part consists of untwinned but polarizing grains of calcite and contains throughout faintly reddish specks of dusty hematite. The grain diameter ranges from 0.02 to 0.047 milli-

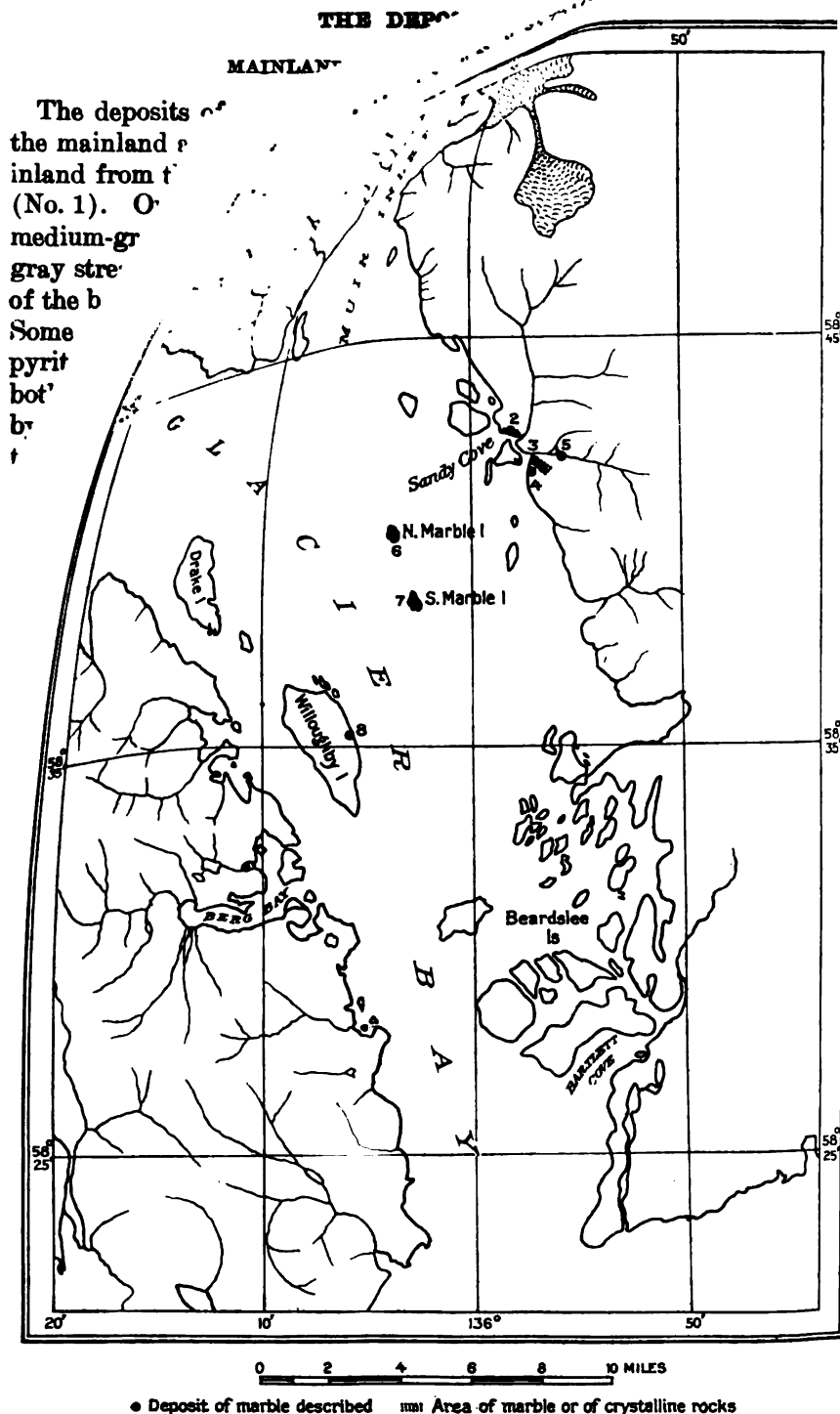


FIGURE 1.—Map showing marble deposits examined on mainland and islands in Glacier Bay. From Coast and Geodetic Survey chart 8306.

meter, with an estimated average of 0.024 millimeter. The transparent parts consist of twinned calcite, of a grain diameter of 0.047 to 0.4 millimeter, with an estimated average of 0.725 millimeter. The texture is therefore fine.

A chemical analysis by R. K. Bailey shows that the rock consists largely of calcite with a little clay material indicated by the insoluble residue:

Analysis of mottled marble from deposit south of Sandy Cove.

Insoluble	2.56
Calcium carbonate	96.16
Magnesium carbonate .....	.89

Three claims, aggregating 3,960 feet in length, were at one time located on the strike of these beds, although little assessment work appeared to have been done up to the time of the writer's visit. The really desirable and commercially valuable stone is probably scarce, and much prospecting will be necessary in order to establish its true extent and value.

The bold cliffs on both sides of the entrance to the cove next south of Sandy Cove and also extending southward from it (No. 4) are composed principally of fine-grained hard, brittle, much fractured gray limestone, cut by many diabase dikes generally 2 to 10 feet thick. Along the contacts between the limestone and the larger dikes the limestone has been locally metamorphosed to white crystalline marble, but not much marble of this sort is available.

In the float near the mouths of the two creeks that flow into this cove, which drain mountain glaciers, there are many boulders of good white and veined marble, and in the canyon of the northern of the two creeks, at about a mile from the mouth of the creek (No. 5), an outcrop of fine-grained grayish-green, partly metamorphosed limestone 10 to 12 feet thick was observed.

Two islands in Glacier Bay, North Marble Island and South Marble Island, are composed wholly of marble, and others, such as Willoughby and Sturges islands, show areas of limestone and marble. The two Marble islands lie about $12\frac{1}{2}$ miles south of the entrance to Muir Inlet and are about $1\frac{1}{2}$ miles apart. According to Coast and Geodetic Survey chart 8306 North Marble Island (No. 6) is about half a mile in length from north to south and less than a third of a mile in greatest width. The highest point is probably about 300 feet above the sea. The marble exposed in this island is yellowish to grayish and is stained along fracture planes. The rock is medium in grain and on weathered surfaces is generally soft and friable. Some portions of the rock are cherty; other portions are brecciated. According to T. N. Dale the grain diameter ranges from

0.05 to 1.05 millimeters but is mostly from 0.25 to 0.75 millimeter. The estimated average is 0.216 millimeter. The Rosiwal measurement gives an average of 0.00977 (about 0.01 inch, or 0.248 millimeter). The Vermont grade is 5 (coarse) and the texture is even.

Thin dikes of a dark fine-grained volcanic rock which appears to be altered spessartite cut the marble beds. The strike of the beds is nearly north. The rock has been jointed and in places shows small folds. The island has been glaciated, but weathering has been active and has produced through solution of material along joint planes and rounding of intermediate portions a bouldery appearance over much of the rock surface. Most of the rock is bare, but in crevices there is a thin cover consisting of mossy soil and vegetation, and hollows where loose material can find lodgment contain small quantities of glacial clay, gravel, and boulders. The island is surrounded by fairly deep water, but the shores are abrupt and afford no harbor.

South Marble Island (No. 7) is similar in character to North Marble Island but is a trifle longer, being about three-fifths of a mile in length. (See fig. 1.) The maximum width is less than half the length, and at one place the island is nearly cut in two at high tide. The maximum height probably does not exceed 250 feet. The marble here is mostly medium-grained white stone, although there is a little veined with gray and a little that is brecciated. A few small inclusions of fine-grained nonmetamorphosed limestone were noted. A thin section examined by T. N. Dale showed a range in grain diameter of 0.025 to 0.75 millimeter, mostly from 0.125 to 0.5 millimeter, with an estimated average of 0.146 millimeter. According to the Rosiwal method the grain diameter averages 0.0077 inch, or 0.196 millimeter. The texture is even, and very little pyrite was noted. The marble takes a good polish. The rock is cut by a few dikes of diabase ranging from less than 1 foot to 3 or 4 feet in thickness. The general strike is north. Joints cut the rock in several directions and are so numerous as probably to interfere with quarrying the marble at the surface. It is possible, however, that all of them may not extend to great depths. Part of the surface is bare and part is covered to a depth of a few inches to 3 feet with glacial debris supporting a growth of mossy turf and shrubs. There is some shoal water in the vicinity of South Marble Island.

Willoughby Island (No. 8) is in the western part of Glacier Bay, about 13 miles north of Icy Strait. It is about $4\frac{1}{2}$ miles in length and 2 miles in width and reaches a height of nearly 1,600 feet. The south half of the island is composed mostly of gray limestone. At about the middle of the east side a small area of marble projects into the bay. This marble is medium grained, of cream and light-gray colors, and brecciated in places. Some patches of chert show on weathered surfaces. Mr. Dale finds that the grain diameter ranges

from 0.112 to 2.8 millimeters, mostly 0.56 to 1.68 millimeters. The estimated average diameter is 0.56 millimeter. By the Rosiwal method the average grain diameter is 0.0181 inch, or about 0.46 millimeter. The grain form is uneven.

The marble is cut by dikes of greenish-gray micaceous, pyritiferous rock, probably dacite, and is jointed. In some places the joints are closely spaced, but in others there are masses of marble that show no joints for 20 to 30 feet. The gray brittle limestone south of the marble outcrop is closely fractured and jointed. The exposed marble extends for about 500 feet along the shore and rises to a height of 60 to 70 feet above the water. Near the shore the surface of the marble shows glacial grooves and striae. Back of the wave-washed exposure there is a growth of shrubs and small trees.

CHICHAGOF ISLAND.

The eastern shore of Chichagof Island from Peril Strait northward to Icy Strait is composed largely of Paleozoic rocks, including limestone, sandstone, phyllite, schists, and greenstone lavas and tuffs. Between Peril Strait and Point Augusta there is considerable limestone and some marble. The most promising deposits were noted in Tenakee Inlet and in Basket Bay and vicinity.

TENAKEE INLET.

In the north side of Tenakee Inlet, from 1 to 2 miles east of Tenakee post office, marble is exposed at several places, in some of which it forms low bluffs 30 to 50 feet above the beach. On the banks of the large creek that flows into the inlet about a mile east of the village (No. 9), from a quarter to half a mile above the mouth of the creek, the marble forms low steep bluffs. Here it is coarse grained and much fractured, and some of it is schistose. The color is mostly nearly white, but some of the rock, especially the schistose parts, is white and green. This deposit was at one time located as a marble claim by persons sojourning at the Tenakee hot springs. On the beach, about $1\frac{1}{2}$ to 2 miles east of Tenakee post office (No. 10), the marble exposed is brittle and hard and ranges from white to gray in color, some being gray and white banded, and there is also a little that shows mottlings of green and pink. It is generally of medium grain, but some, particularly the mottled stone, is fine grained. Specks of pyrite are present in places.

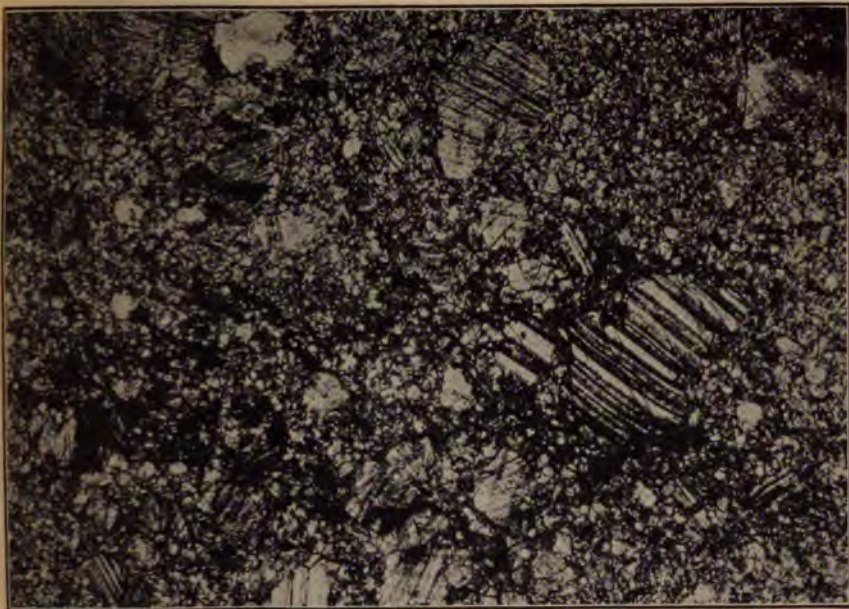
Mr. Dale examined microscopically two thin sections of the fine-grained marble from this area. One section, cut from a pale yellowish-white specimen, showed a grain diameter of 0.02 to 0.14 millimeter, mostly 0.03 to 0.094 millimeter, and the estimated average is 0.04 millimeter. The Rosiwal measurement showed an average

grain diameter of 0.0014 inch, or 0.0355 millimeter. This specimen is of even texture, but it contains streaks of pyrite in fine spherules and particles, roundish grains of feldspar and quartz reaching a diameter of 0.125 millimeter, and chlorite. The other specimen, which is white marble with faint yellowish bands, showed an abnormal texture, appearing to be a brecciated calcite marble with calcitic cement and to have been subjected to secondary compression. (See Pl. VI, A.) The groundmass of this specimen showed a grain diameter ranging from 0.0378 to 0.25 millimeter, mostly 0.047 to 0.14 millimeter, with an estimated average of 0.073 millimeter, and is to be classed as fine textured. The fragments disseminated in the groundmass are calcite plates having a grain diameter of 0.62 to 2.25 millimeters, with an estimated average of 0.89 millimeter, and are thus of coarse texture. The calcite of the groundmass is closely twinned, and the brecciated plates show curved twinning and retwinning produced by later movement.

The general strike of the rocks is northward, but the bedding is obscured by the folds and fractures, which are very prominent. The fractures are locally so close together that good hand samples can hardly be obtained from surface material. The marble is cut and impregnated by so much altered volcanic rock as to be in most places of little value, but it may be possible to find here and there material suitable for quarrying. Except where exposed on the beach and in stream cuttings the marble is concealed by a heavy forest growth.

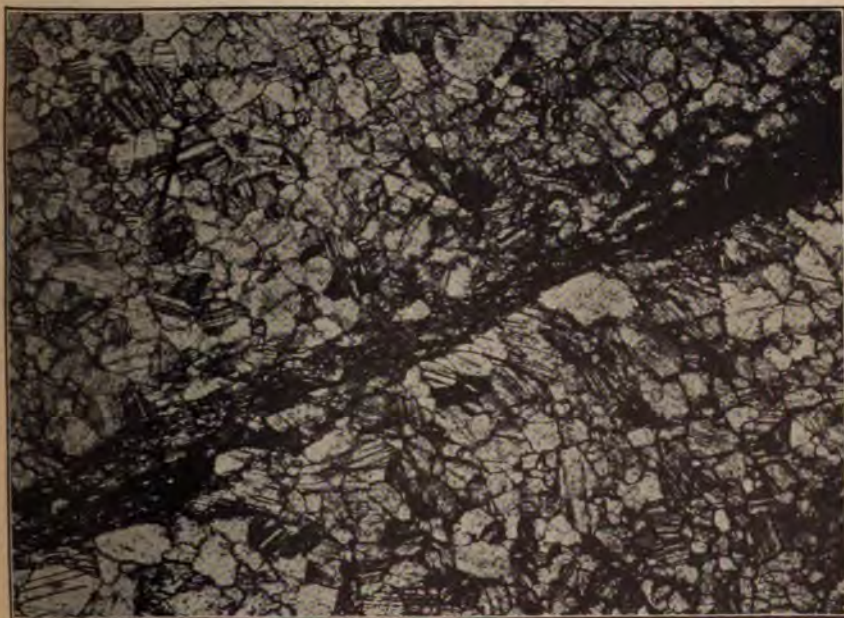
BASKET BAY AND VICINITY.

Basket Bay (No. 11) is a short, narrow arm of Chatham Strait about 8 miles south of Tenakee Inlet. Although only about a third of a mile wide and $1\frac{1}{2}$ miles long, it affords good anchorage and good protection to vessels. The marble in the vicinity of Basket Bay is chiefly of fine grain. With reference to color there are four principal varieties—gray, gray and white banded, white, and dark blue with calcite streaks. On the southwest shore of the bay the marble is exposed almost continuously. Here the rock is massively bedded but weathers to thin spalls. The strike is N. 30° W., and the dip is steep toward the northeast. Myriads of small fractures cut the surface rock into small rhombohedral blocks, and the seamed condition extends up into the bluffs back of the bay. The marble is cut and impregnated in many places with seams of altered hornblende andesite. There is probably an enormous quantity of marble in this vicinity. The deposit on the southwest shore of Basket Bay appears to extend to the top of the 2,400-foot peak southwest of the bay. The appearance of the weathered summit and slopes of the 4,000-foot mountain to the northwest, 4 miles from the head of the bay, may be composed of limestone or marble, as it strongly suggests cal-



A. PHOTOMICROGRAPH OF THIN SECTION OF WHITE MARBLE FROM CHICHAGOF ISLAND, TENAKEE INLET.

View shows fine-grained groundmass containing coarser fragments of brecciated calcite with curved twinning. Magnified 10 diameters.



B. PHOTOMICROGRAPH OF THIN SECTION OF WHITE MARBLE WITH LIGHT-GRAY VEINS FROM TOKEN.

The section is crossed by a band of very fine untwinned dolomite (?) along which shearing has taken place and shows also the uneven texture of the marble. Magnified 15 diameters.



**A. SCHISTOSE MARBLE ON WAVE-SCoured BEACH OF CHATHAM STRAIT,
ADMIRALTY ISLAND, NORTH OF MARBLE COVE.**



**B. NEAR VIEW OF WAVE-SCoured MARBLE ON BEACH OF CHATHAM STRAIT,
CHICHAGOF ISLAND, SOUTH OF BASKET BAY.**

careous rock, and the mountain is directly in the line of strike between the Basket Bay and Tenakee marble areas, but it is more likely to be a mass of light-colored granite whose intrusion into limestone beds has produced the adjacent areas of marble.

Two samples of marble from Basket Bay were examined microscopically by T. N. Dale. One, a fine-grained gray marble with white calcite bands and streaks crossing the banding, was found to be graphitic. The graphitic laminae, which constitute most of the section, consist partly of untwinned magnesian calcite. The grain diameter ranges from 0.03 to 0.066 millimeter and the estimated average is 0.036 millimeter. The white streaks, which reach 0.25 millimeter in width, consist of twinned calcite having a grain diameter of 0.037 to 0.2 millimeter and an estimated average of 0.064 millimeter. A few quartz grains were noted in this material. A calcite streak crossing the banding is 0.5 to 1.25 millimeters wide and consists of twinned calcite having a grain diameter of 0.185 to 1.1 millimeters and an estimated average diameter of 0.337 millimeter. An analysis by R. K. Bailey is as follows:

Analysis of graphitic marble from Basket Bay.

Insoluble	28.19
Calcium carbonate (CaCO_3)	63.68
Magnesium carbonate (MgCO_3)	8.90

The other sample, a fine-grained grayish-white marble, showed a grain diameter of 0.05 to 0.37 millimeter, mostly 0.125 to 0.25 millimeter, with estimated average of 0.1 millimeter. The Rosiwal measurement gave an average grain diameter of 0.0037 inch, or 0.094 millimeter. The texture of this sample is even, but the grains are elongate.

Marble beds form the shore of Chatham Strait southward from Basket Bay to the next small cove, a distance of more than a mile. Some of the marble exposed here (No. 12) is of excellent quality and is susceptible of a good polish. It is all fine grained and is generally banded with bluish gray and white. (See Pl. VII, B.) Micrometer measurements by T. N. Dale of a sample of this marble indicate that the grain diameter ranges from 0.047 to 0.24 millimeter, mostly 0.094 to 0.02 millimeter, and the estimated average is 0.079 millimeter. The Rosiwal measurement gave an average diameter of 0.0031 inch, or 0.0752 millimeter. The texture is even. Minute quartz grains are rarely present, and some pyrite in minute particles arranged in parallel streaks altering to limonite were noted.

The beds strike N. 30°–35° W. and dip steeply northeast. The rock is cut by many minute fractures above tide level, has been closely folded, and commonly shows flow structure. Small faults are strik-

ingly brought out on polished surfaces. The banding, the folds, and the flow structure are beautifully shown on the wave-scoured beach. Nowhere, however, is the marble for any considerable distance free from joints or from basaltic dike material. The bluffs are steep here and are surmounted with forests.

At a point on the north side of the small cove (No. 13), the marble is mostly fine grained and white, although there is a little interbedded light-gray rock. It is rather soft and friable above tide level in the cliffs, where it has been subjected to severe weathering, but it presents a handsome appearance. A thin section of the fine-grained white marble with faint green cloudings was examined by T. N. Dale, who found the grain diameter to range from 0.025 to 0.35 millimeter, but mostly from 0.125 to 0.25 millimeter, and estimated the average at 0.08 millimeter. The grade is a little finer than Vermont grade 2 (very fine). The texture is even.

The characteristic jointing, fracturing, and intrusion by dikes have affected the beds here in no less degree than in other places along this shore. At the head of the cove is exposed a fine-grained gray and white banded marble, which was traced three-quarters of a mile or more up the creek that empties into this cove. The beds are massive where unweathered, as, for instance, below high-tide level or below the level of the creek, but they show much fracturing where exposed to the weather. This condition suggests that the action of frost may have played an important part in opening fractures caused by strains. Flow structure and conspicuous folding are common. The whole mass seems to have been impregnated with thin dikes and stringers of hornblende andesite after the folding occurred.

In order to appraise the value of this interesting area of marble, considerable prospecting with the core drill will be necessary, trails must be cut into the interior, and the marble must be explored on the slopes of the mountains.

ADMIRALTY ISLAND.

The shores of Admiralty Island from Mansfield Peninsula to Chaik Bay and from Pybus Bay to the head of Seymour Canal are made up largely of limestone and schist. The general distribution of rocks along the shore line of this island is shown in Bulletin 287,¹ although slight modifications should be made as a result of observations during the study of marble deposits. For instance, the "Mar-

¹ Wright, C. W., A reconnaissance of Admiralty Island, Alaska: U. S. Geol. Survey Bull. 287, pp. 138-154, pl. 33, 1906. This bulletin is out of stock at the Survey but may be purchased from the Superintendent of Documents, Washington, D. C., for 75 cents.

ble Bluffs" on Chatham Strait, nearly opposite Tenakee Inlet on Chichagof Island, have been found to be composed of quartz monzonite, a light-colored granitic rock, instead of marble, as heretofore popularly supposed. In parts of the limestone belts the limestone has been metamorphosed to marble, some of which is of good quality and some of which is schistose. Exposures of marble were examined on the west shore between Cube Point and Point Hepburn, also south of "Marble Bluffs" and in Hood Bay, and search for marble was made at many intermediate points and in Pybus Bay.

POINT HEPBURN.

From 1 to 1½ miles north of Point Hepburn (No. 14) extends an area of medium to coarse grained schistose marble, which is white with gray, green, and black schistose bands. It includes nodules and lenses of fine-grained rock that probably contain magnesium carbonate. In places along the schistose planes pyrite is abundant. The rock occurs generally in beds 2 to 5 feet thick, but owing to the schistose structure it weathers to thin bands on the edges of the beds. The beds are cut by quartz veins and are interbedded with green schist.

Two samples of marble from this exposure were examined under the microscope by T. N. Dale and G. F. Loughlin. In one, a schistose green and white banded marble, the grain diameter ranged from 0.075 to 0.75 millimeter, mostly 0.25 to 0.5, with an estimated average of 0.187 millimeter. Much close twinning of the calcite is evident. The schistosity is shown in the section by the distribution of the grains of quartz and feldspar and scales of chlorite and muscovite, which form a series of bands. These bands contain also grains of titanite.

The other sample, a greenish marble, displays a very irregular texture. It consists of several small bands of fine and of coarse texture, some of them with epidote and hornblende and small grains of titanite, others with grains of feldspar and quartz, and some with large plates of calcite, one measuring 3 millimeters. In one of the coarser bands the quartz and calcite grains measure as much as 1.12 millimeters. The small beds are crossed at an angle of 25° by planes of slip cleavage. Much close twinning is present in the larger calcite grains. This is a calcite marble with quartz, feldspar, epidote, hornblende, and pyrite. The rock takes a fair polish, but owing to the presence of the schistose bands the polish is uneven.

The beds strike N. 50° W. and stand almost vertical. There has been some close folding, but for the most part the bedding or schist planes are flat. This exposure now forms a low bluff for about half a mile along Chatham Strait, and the direction of strike carries the

beds into a prominent ridge toward the southeast. On the beach the beds are not well situated for quarrying, as the bluff is steep and high tide reaches its base, but if the quality of the material should warrant exploitation, a quarry could probably be opened in the slope of the ridge and the product trammed to the cove near Point Hepburn, where anchorage for boats of medium draft is available.

MARBLE COVE AND VICINITY.

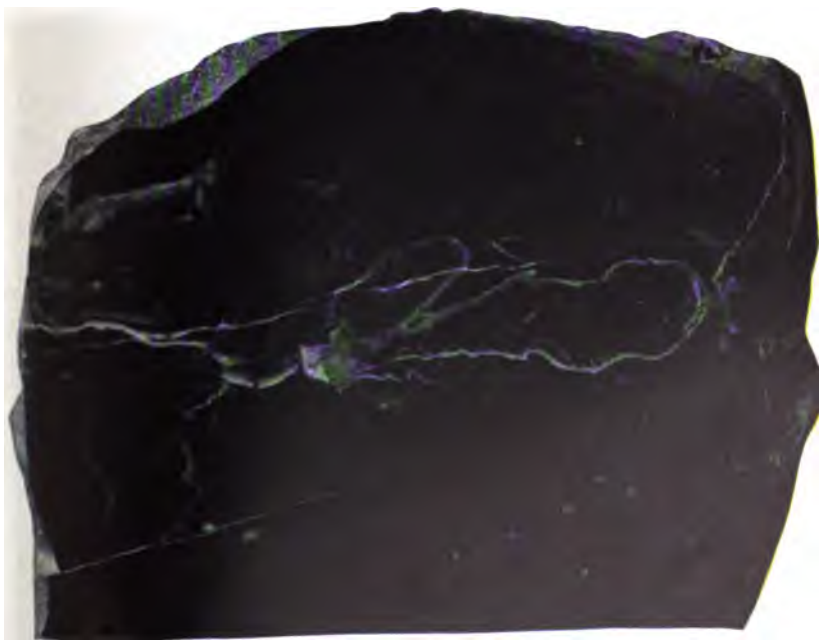
On Chatham Strait from a point 4 miles south of "Marble Bluffs" to a point 1 mile north of a small notch in the shore, which will here be called Marble Cove, there is a deposit of marble that possesses considerable scientific interest and possibly some commercial value. At this locality (No. 15) the marble is interbedded with bands of gray and green mica schist and white to gray variously banded quartz schist. The marble layers range from 1 inch to 3 or 4 feet in thickness. The bands of mica schist are generally 1 inch to 5 or 6 inches thick, and some of the bands of quartz schist are a little thicker but rarely exceed 1 foot. The marble is medium grained and is gray, white, pink, and green. All of it is susceptible of a fair polish, and the quartzite takes a glassy polish. The beds strike N. 60°-65° W. and are nearly vertical. They are cut by small dikes of dark-green hornblende dacite which send out stringers between the schistose layers. Folds are also exhibited by the varicolored bands. (See Pl. VIII, A.) This outcrop is exposed in a strip about 50 feet thick along the beach for a quarter of a mile or more and is partly submerged at high tide. (See Pl. VII, A.) It is bounded by a bluff which also contains alternate bands of marble and schist, the schist predominating. In strike with these beds, 1 to 1½ miles toward the southeast (No. 16), a similar body of banded marble, schist, and quartzite is exposed by a steep mountain stream.

Several thin sections of marble from this locality were examined by T. N. Dale and G. F. Loughlin. One section from a medium-grained white band in a schistose mass showed a grain diameter of 0.05 to 1.12 millimeters, mostly 0.12 to 0.62 millimeter, with an estimated average of 0.23 millimeter. The texture of this rock is uneven. Sparse grains of quartz, pyroxene, and tremolite were noted, also a few lenses of these minerals reaching 3 millimeters in length. The material is a slightly quartzose and pyroxenic calcite marble.

Another section showed medium-grained schistose material, with alterations of white and green bands. The white band consists of calcite having a grain diameter ranging from 0.075 to 0.62 millimeter, but mostly from 0.12 to 0.37 millimeter. The estimated average diameter is 0.166 millimeter. It has an uneven texture. The calcitic portion contains many particles and streaks of tremolite and pyroxene with a little quartz. On either side of the calcite band is a band of



4



5

4 SCHISTOSE VARICOLORED MARBLE FROM CHATHAM STRAIT BEACH OF ADMIRALTY ISLAND,
1 MILE NORTH OF MARBLE COVE.

5 FINE-GRAINED BLACK MARBLE (BLUE-BLACK LIMESTONE) FROM VERMONT MARBLE CO.'S PROP-
ERTY, TOKEEN, MARBLE ISLAND.

epidote 0.1 inch wide. This rock is a calcite marble with pyroxene, epidote, tremolite, and quartz. In a section of the quartz schist the quartz grains form minute specks as much as 3 millimeters in diameter. The average grain, except in the coarse streak, is about 0.12 millimeter. Thin streaks of carbonate and augite give the schistose character. One band noted was composed chiefly of pale-green augite, 1 millimeter in maximum length but averaging 0.2 millimeter, rimmed in places by a little common hornblende. The other main constituent is quartz. A few grains of pyrite and titanite are present.

Another sample of medium-grained schistose material with white and green bands, but coarser than the material described in the preceding paragraph, shows a grain diameter of 0.125 to 1.37 millimeters, mostly 0.25 to 0.75 millimeter, with an estimated average diameter of 0.332 millimeter. The texture is uneven, the rock containing sparse pyroxene grains 0.05 to 0.37 millimeter in diameter. A central light-greenish band or vein averaging 0.1 inch in width crosses the section; it consists of green pyroxene with a little quartz and a very little pyrite. Minute specks of titanite are common. This band is crossed at right angles by numerous microscopic joints.

Still another section showed medium-grained greenish pyroxenic marble in which the grain diameter ranges from 0.074 to 1.3 millimeters, mostly 0.16 to 0.74 millimeter, and the estimated average is 0.24 millimeter. The texture is uneven and irregular. The calcite is closely twinned, and many of the grains have curved twinning, indicating secondary movement. The section contains sparse grains of pyroxene 0.17 to 1.5 millimeters in diameter, a few quartz grains, a quartz lens 1.25 millimeters long, and a little tremolite.

The wave-washed beach exposures of this banded rock afford some sections of very attractive material, and if it can be quarried advantageously it should be possible to obtain a large quantity of stone here that might be suitable for certain classes of interior decorative work. This rock, which consists of alternating layers of material of variant degrees of hardness, is not so easily sawed and polished as a more homogeneous rock. However, large blocks of similarly banded schistose marble found on Moira Sound, Prince of Wales Island, have been cut and polished and yielded very handsome finished slabs.

About a quarter of a mile to a third of a mile north of Marble Cove occurs another strip of attractive marble. The beds here also strike N. 60°-65° W. and stand nearly vertical. The total width (or thickness) of the exposure is 115 to 130 feet. It extends 500 to 600 feet along the beach and in places forms a bluff 40 feet high. From 40 to 50 feet of these beds at the northeast side consist of medium-grained gray marble, closely banded with thin dark-gray layers. The southwest 75 to 80 feet is coarse-grained yellowish

white and greenish-white marble. Dikes of basaltic rock cut the beds, but not so closely as to interfere seriously with quarrying. A section of medium-grained gray and white banded marble from this locality showed a grain diameter of 0.114 to 1.71 millimeters, mostly 0.38 to 0.95 millimeter, with an estimated average of 0.38 millimeter. According to the Rosiwal measurement, the average grain diameter is 0.014 inch, or 0.355 millimeter. The texture is slightly uneven. Much close twinning was noted, also a few particles of pyrite(?).

At the north side of the entrance to Marble Cove (No. 17) is exposed a fine-grained white marble. The rock strikes N. 60°-65° W. but is so badly fractured that the bedding is indistinct. The quantity of stone of this grade seems to be small, as toward the north the material passes into coarser yellowish marble. A section of this fine-grained white marble shows that most of the crystals are twinned. The grain diameter ranges from 0.05 to 0.325 millimeter, mostly between 0.125 and 0.25 millimeter. The estimated average diameter is 0.096 millimeter. The texture does not show interlocked particles. There are some cloudy (graphitic?) areas of calcite as much as 0.4 inch long and 0.1 inch wide in which the twinning planes bisect the acute angle of the cleavage rhomb and some of the grains are very large. The following analysis of this sample, by R. K. Bailey, shows that it is high in magnesium:

Analysis of white marble from Admiralty Island, north side of Marble Cove.

Insoluble matter.....	0.91
Calcium carbonate (CaCO ₃).....	61.11
Magnesium carbonate (MgCO ₃)--	39.10

Another deposit of marble was noted on this part of the Admiralty Island shore about a third of a mile south of Marble Cove, just south of the mouth of a large creek. The marble is of medium grain and comparatively hard. Some of it is white and some is white and gray banded. Both varieties take a good polish. The outcrop extends for half a mile or more along the beach and forms a bluff about 50 feet high, back of which is a flat wooded terrace several hundred feet wide, developed on the marble. The marble at the base of the bluff is of a dazzling white color, having been smoothed and polished by the surf. The rock is massively bedded and strikes northwest. Joints and dikes cut the beds but not closely enough to interfere with quarrying. A quarry could probably be opened conveniently on the terrace above the beach, but as there is no harbor at this point boats could be loaded only at times of calm water.

Two samples of marble from the deposit south of Marble Cove were examined microscopically by T. N. Dale and G. F. Loughlin. A sample from the gray beds showed a very uneven texture, the stone being made up of more or less irregular small bands of three differ-

ent grades of texture. By micrometer measurement the finest-textured material has a grain diameter of 0.03 to 0.14 millimeter, with an estimated average of 0.05 millimeter. This fine material is shown on two opposite edges of the section. The next, by micrometer measurement, has a grain diameter of 0.1 to 0.25 millimeter, with an estimated average of 0.125 millimeter. The coarsest-textured material has a grain diameter of 0.15 to 1 millimeter, with an estimated average of 0.29 millimeter. Fine-grained streaks cut some of the large grains and are due to shearing about parallel to the bedding. This marble contains some weakly pleochroic white to pale-brown mica, mostly confined to short, discontinuous layers, and a few isolated flakes impregnating carbonate grains, probably nearer muscovite or phlogopite in composition than biotite, and a few tremolite grains. Some of the bands carry minute black particles, possibly oxidized pyrite or possibly graphite.

A section of the white marble shows a grain diameter of 0.28 to 1.40 millimeters, mostly 0.56 to 1.122 millimeters, with an estimated average of 0.466 millimeter. The section also shows a vein of calcite 0.56 millimeter thick, with streaks of fine and coarse grained calcite at right angles to this vein. The twinning is very close, and some of the grains are not transparent but clouded with dusty inclusions of carbon (?). An analysis by R. K. Bailey is as follows:

Analysis of white marble from deposit south of Marble Cove.

Insoluble matter.....	3. 61
Calcium carbonate (CaCO_3).....	95. 44
Magnesium carbonate (MgCO_3).....	1. 45

A section of blue and white speckled marble taken from the beach near the diorite area on the south was examined by Messrs. Dale, Loughlin, and Mertie. The rock seems to consist partly of twinned dolomite and partly of twinned calcite. The grain diameter ranges from 0.12 to 1.5 millimeters, mostly 0.25 to 0.75 millimeter, with an estimated average of 0.35 millimeter. The grain is medium, and the texture is uneven. Scattered through the marble are fine to coarse dark specks which appear to be segregations of olivine altered to serpentine and magnetite. A little diopside is associated with the olivine. Mr. Mertie found also carbonaceous matter intimately mixed with forsterite and in places associated with sulphides. The hand specimen shows pyrite grains. An analysis of this rock by R. K. Bailey follows:

Analysis of blue and white speckled "marble" south of Marble Cove.

Loss on ignition.....	33. 82
Insoluble matter (SiO_2 and R_2O_3).....	9. 71
Calcium oxide (CaO).....	33. 60
Magnesium oxide (MgO).....	19. 08

Adjoining this deposit on the south is an area of altered quartz diorite, shown on Plate XXXIII of Bulletin 287 as extending southward nearly to Parker Point. In the area extending southward from Parker Point to Chaik Bay schist predominates and no desirable marble was noted except at Hood Bay.

Wright¹ states that certain parts of the limestone belts on the west coast of Admiralty Island, mapped during his reconnaissance, have been converted into marble, some of which is sufficiently massive and even grained to make an excellent building stone, though, perhaps, not fit for ornamental purposes, but that large slabs or columns probably can not be obtained owing to the system of joints. Referring to the areas between Point Hepburn and Marble Cove, he states that a mass of marble forms the rock on the west shore opposite Tenakee Inlet for a distance of 8 miles and, being easily accessible, may prove to be of economic value. According to Wright, the marble contains bands rich in dolomite, has a fine granular texture, a white to light-gray color, and in places a banded appearance. The studies of the writer have shown that this marble area is not continuous but is interrupted by areas of monzonite, diorite, and schist; that much of the marble is schistose, which probably accounts for the banded appearance mentioned by Wright; and that the deposit contains much coarse-grained as well as fine-grained marble.

HOOD BAY.

Some fine-grained white marble was noted in two places on the northeast shore of Hood Bay (No. 18), almost due east of Distant Point. In hand samples this is a very beautiful marble, which takes a good polish, but its availability in large blocks and in large quantity is questionable. Mr. Dale finds that the grain diameter of this marble ranges between 0.05 and 0.3 millimeter but mostly between 0.125 and 0.2, and estimates the average at 0.091 millimeter. The grade is thus a trifle finer than 2 (very fine). The texture appears even. Mr. Dale mentions the presence of grains of quartz and feldspar from 0.037 to 0.148 millimeter in diameter, but these were not recognized by Mr. Loughlin.

The marble is associated with schist and becomes schistose in the direction of the strike, which is apparently N. 70° E. The beds are rather slabby and dip about 20° SE., although the angle of dip is variant. The surface rock is jointed into small rectangles, a few inches to 2 or 3 feet across. Veins and eyes of quartz were noted in the marble. One of the exposures measured about 500 feet between its borders of schist and possibly 100 feet on the strike, between mean

¹ Wright, C. W., A reconnaissance of Admiralty Island, Alaska: U. S. Geol. Survey Bull. 287, p. 154, 1906.

tide level and the wooded bluff. The rock farther up the hill was found to have a schistose texture. At the other exposure, about a quarter of a mile to the southeast, the material is similar in character but has been much fractured and carries considerable quartz in eyes and veins.

CHAIK, PYBUS, AND GAMBIER BAYS.

Wright¹ states that small belts of marble occur at Chaik Bay, on the west side of the island, and at Gambier and Pybus bays, on the southwest side. Neither Chaik Bay nor Gambier Bay was examined by the writer. On the west side of Pybus Bay, about 2½ miles from the entrance, is a small area of gray crystalline limestone with bands and nodules of chert. The beds strike north and dip 72° E. At the end of a small point where the beds are exposed they are thin and much fractured, but in an overhanging cliff facing a small cove they appear to be more massive. These beds are abundantly fossiliferous, and in the cliff the fossils appear in relief on the weathered faces of the beds. A collection of these fossils made by the writer contained the following species, as determined by George H. Girty, who states that they are supposed to be of Artinskian age, or well along in the Carboniferous:

Lot 38. Fossils from west side of Pybus Bay, 1913:

- Batostomella* sp.
- Camarophoria* aff. *C. margaritovi*.
- Chonetes* aff. *C. morahensis*.
- Productus* aff. *P. timanicus*.
- Productus* aff. *P. gruenewaldti*.
- Productus* semireticulatus.
- Productus* aff. *P. multistriatus*.
- Productus* sp.
- Tegulifera?* sp.
- Dielasma* sp.
- Rhynchopora* aff. *R. nikitini*.
- Spirifer* aff. *S. cameratus*.
- Spiriferella?* arctica.
- Squamularia* aff. *S. perplexa*.
- Modiola?* sp.
- Murchisonia?* sp.

At several points on the west side and on the east side near the head of Pybus Bay is exposed a much fractured cherty magnesian limestone containing crinoid stems and small brachiopods. The shore line of Pybus Bay, except at the mouth of the bay, is mapped by Wright² as limestone and schist, but by far the greater part of the west shore line is made up of a dark metamorphosed shale. This

¹ Wright, C. W., op. cit., p. 154.

² Idem, pl. 33.

dark rock is regarded by Edwin Kirk as of Triassic age. No rock that could be termed commercial marble was discovered in Pybus Bay.

KUPREANOF ISLAND.

Beds of limestone interstratified with schist have been noted on Kupreanof Island on the west side of Duncan Canal. Among the Castle Islands beds or lenses of cherty limestone containing veins of calcite were noted by the writer to be nearly in strike with a lens of barite,¹ with relations suggesting that the barite may have been formed through the replacement of limestone. In the autumn of 1914 W. C. Waters forwarded to the Survey samples of partly metamorphosed light and dark grayish-blue limestone with bands and patches of white calcite from the north side of the west arm of Duncan Canal and light-gray finely laminated marble from the south side of the west arm of Duncan Canal. Although the charts of the Coast and Geodetic Survey do not show which is the "west arm" of Duncan Canal, it is believed that this arm is the shallow one that joins the main body of water about 4 miles south of the Castle Islands, and it is therefore indicated as locality 19 on the accompanying index map (Pl. I). The grain of the samples from the north side of the arm is irregular, ranging from moderately fine in the mass to moderately coarse in the calcite streaks. The light grayish-blue sample from the south shore is medium and more even grained but shows numerous coarser calcite crystals and a few specks of pyrite. According to Mr. Waters these deposits are exposed along the beach for about $1\frac{1}{2}$ miles and lie about 2 miles from deep water. The rock strikes northwest and dips about 45° SW. The associated beds are shale and schist, and the overburden consists of 6 to 8 feet of moss and soil. The limestone and marble are themselves schistose, and the samples submitted appear to be of no particular merit, but the occurrence is noted here in the hope that it may lead to further and better discoveries in this locality, which is centrally situated and near steamship routes.

NORTHERN PART OF PRINCE OF WALES ISLAND.

POINT COLPOYS.

Much of the northern shore line of Prince of Wales Island facing Sumner Strait is formed by fine-grained to dense bluish-gray limestone, more or less metamorphosed and cut and impregnated by igneous rock. West of Point Colpoys is an area of marble (No. 20) that has appeared sufficiently attractive to the prospectors, Woodbridge & Lowery, to warrant them in staking out claims. The mar-

¹ Burchard, E. F. A barite deposit near Wrangell, Alaska: U. S. Geol. Survey Bull. 592, pp. 109-117, 1914 (Bull. 592-D).

ble is fine grained and comprises mottled and white varieties, the mottled greatly predominating. Reddish stains along fracture planes give to some portions of the marble an attractive appearance. Some of the marble is brecciated and conglomeratic, with white and red contrasts. The bedding is indistinct, and the rock is closely fractured and jointed on the beach exposures. Numerous thin dikes of altered olivine basalt cut the deposit in several directions; the most prominent system of dikes strikes about N. 40° W. This deposit is exposed along the beach for a quarter of a mile or more and extends back into the interior an undetermined distance. The quantity of the marble available is probably small, and it is likely that owing to the multitude of intersecting dikes and fractures no large blocks can be obtained. This portion of Prince of Wales Island near the shore is low and is covered with a swampy forest growth.

Another group of claims owned by Woodbridge & Lowery lies about 2 miles west of Point Colpoys (No. 21, Pls. I and III). The rock here is fine-grained limestone, only slightly if at all metamorphosed. It is all much brecciated and displays a variety of colors, including white, red, gray, and black. Fractures and joints are very numerous, and the rock is cut by many dikes which have been faulted and contorted. The exposure extends along the beach for one-third mile or more, but is obscured inland by a heavy forest growth.

RED BAY.

At the east side of the entrance to Red Bay, along the west shore of Bells Island, fine-grained slightly metamorphosed limestone is exposed for about half a mile (No. 22). Below high-tide level this stone is generally light colored on fresh surfaces, with white and pink mottled effects predominating; above high-tide level darker colors, such as grays and blues, predominate. Some handsome mottled and brecciated material is present here. The deposit is badly fractured and is intersected closely by dikes of andesitic and basaltic rock. Woodbridge & Lowery have located a claim extending 1,500 feet along the shore and 600 feet inland known as the East Side claim. There is a heavy growth of forest and underbrush above tide level.

Marble appears also on the west shore of Red Bay about 2½ miles from the mouth, near the head of the bay, and beyond in the vicinity of Red Bay Mountain.

The marble on the west shore of Red Bay (No. 23) is fine grained and is mostly light colored, showing white, faintly to strongly clouded gray, and grayish-blue shades. The part exposed at the surface is rather soft. The beds are cut by several dikes of metadiabase, most of which are only a few inches thick, though one measuring 4 to 6 feet was noted. Thin irregular stringers from some of these dikes

penetrate the marble in all directions. The marble exposed on the beach is jointed and, where weathered, shows slightly schistose planes that strike north-northeast. One bed of partly metamorphosed dark-bluish limestone, much fractured and having the seams filled with calcite, was noted interbedded with the marble.

On account of the softness of the samples, which were of necessity taken from the water-soaked surface, it was difficult to make thin sections of this marble. Two sections, both light colored, fine grained, and more or less fragmentary, were examined by T. N. Dale. One section showed a grain diameter of 0.02 to 0.141 millimeter, with some exceptionally large particles, but mostly between 0.047 and 0.094 millimeter. The texture is uneven. The Rosiwal measurements showed an average grain diameter of 0.001755 inch, or 0.04457 millimeter. The other section shows a grain diameter ranging between 0.02 and 0.2 millimeter, but mostly between 0.03 and 0.094 millimeter, and the estimated average diameter is 0.05 millimeter.

Claims aggregating 80 acres, extending about half a mile parallel to the beach and one-fourth mile inland, were located on this deposit by Woodbridge & Lowery. In 1912 some prospecting was done on the beach by hand and by blasting with black powder, and back of the beach, within the woods, the soil was stripped off and the surface of the marble was bared in several pits and trenches, some of which are 140 feet long. The cover is 2 to 4 feet or more thick. It is reported that in 1915 the Vermont Marble Co. opened a quarry on these claims about a quarter of a mile back from the beach. The marble is said to be cream-colored with rust-colored veins, like the Grecian Skyros marble. The beds are reported to stand vertical and to be much fractured, so that the blocks obtainable are relatively small.

On the west shore of Red Bay about three-quarters of a mile south of the Woodbridge & Lowery claims and separated from them by a body of dark intrusive rock is an exposure of fine-grained light-gray to dark-gray marble. Samples from an exposure in the woods about 500 feet back from the beach and 60 to 80 feet above high-tide level are mottled. The weathered marble on the beach is very soft and appears slightly schistose, with the gray veins parallel to the schistosity.

At the head of Red Bay and above the head of the bay, between Red Bay Mountain and the head of a small lake about $1\frac{1}{2}$ miles long which lies south of the bay, there are deposits of marble (Nos. 24 and 25) on which the Vermont Marble Co. has located claims. It is probable that this belt of marble extends southwestward nearly if not quite to Dry Pass. The mass of marble at Winter Harbor has been traced a mile or more northeastward from Dry Pass.



THE QUARRY OF ALASKA MARBLE CO. AT CALDER, PRINCE OF WALES ISLAND.



AN GRAVEYARD ON THE SMALL MARBLE ISLAND AT ENTRANCE TO DRY PASS NEAR SHAKAN.

Photographed at half tide, shows characteristic shore outcrop of marble in this locality.

The deposit at the head of the bay (No. 24) has been tested by drill holes near Little Creek and on the left bank of a small creek between Little Creek and Big Creek. About 25 feet of a $\frac{7}{8}$ -inch core was noted at the latter place in September, 1913, and a small area of perhaps 10 square yards of the surface rock had been exposed by stripping. The marble is white with gray veins, of medium grain, and rather soft, so far as shown by the exposure and the core. The drill hole intersected a $1\frac{1}{4}$ -inch dike of hornblende andesite(?) containing pyrites. Mr. Dale finds that the grain diameter of the marble ranges from 0.074 to 0.925 millimeter, mostly 0.148 to 0.555 millimeter, and estimates the average to be 0.216 millimeter. The Rosiwal measurement gave an average grain diameter of 0.0079 inch, or 0.2 millimeter. The texture is uneven. The marble is covered by a heavy mold and forest growth. It lies at a distance of a mile or more from deep water, as the upper end of Red Bay consists of mud flats at low tide.

On the southeast shore of the bay near the head, facing the mud flats, are exposures of hard fine-grained subcrystalline, partly metamorphosed limestone of light-gray and cream colors with mottled effects and also showing banded gray and blue phases. A thin section of this limestone was found by Mr. Dale to be composed of polarizing untwinned grains of calcite from 0.004 to 0.043 millimeter in diameter with a few lenses of twinned calcite grains. This rock is cut by andesite dikes and more or less fractured. In order to ascertain whether this rock was limestone or dolomite the following determinations were made by R. K. Bailey:

Analysis of limestone from head of Red Bay.

Insoluble matter	1.70
Calcium carbonate (CaCO_3).....	93.90
Magnesium carbonate (MgCO_3)--	2.59

PORT PROTECTION.

About a quarter of a mile southeast of the head of Port Protection and 1 mile from deep water (No. 26), a mass of limestone forms a divide between two small creeks that flow into the bay. This limestone forms a bluff about 100 feet in height with nearly vertical bedding and a northwesterly strike. The rock consists chiefly of fine-grained gray to nearly white stone, in places partly metamorphosed to marble. It is badly jointed and fractured at the surface and is veined and discolored, especially along the fracture planes.

SHAKAN BAY.

Marble and limestone beds border the northeast shore of Shakan Bay, and the marble is well exposed in the entrance to Dry Pass in two small islands, on which are Indian graveyards (Pl. IX, B).

This marble is now considered to be of Silurian age and to have been altered by the intrusion of a granite mass that lies adjacent to it on the southeast. Claims 2 miles long and half a mile or more wide were located along the coast of Shakan Bay (see fig. 2) in 1905 by the Alaska Marble Co., after considerable prospecting by trenching and drilling to ascertain the extent of the marble and its quality in depth. A quarry has been opened near Calder, at an altitude of

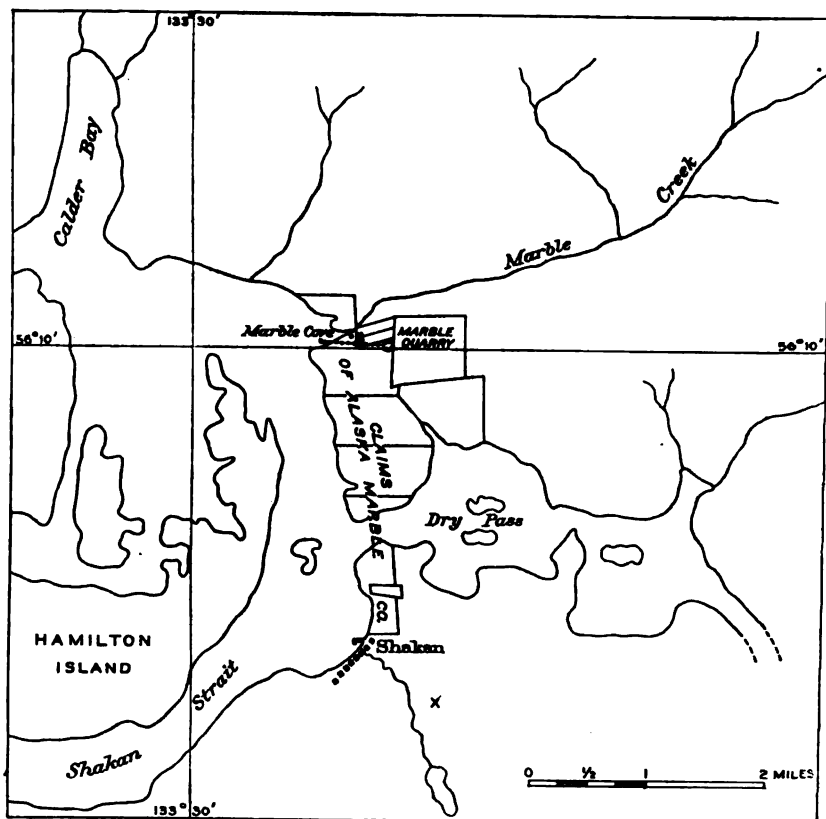


FIGURE 2.—Sketch map showing marble quarry and claims of Alaska Marble Co. on Prince of Wales Island, Shakan Bay.

about 100 feet on the hillside south of Marble Creek, about half a mile above its mouth (No. 27), and an area of 100 by 200 feet has been stripped and quarried to a depth of nearly 100 feet measured on the hillside, about 60 feet below the level of the tramway. (See Pl. IX, A.) A tunnel has also been driven back for a distance of about 25 feet at the southeast corner of the quarry pit.

The quarry is connected with deep water in Marble Cove by an inclined trestle, 3,200 feet in length, on which is laid a standard-gage railroad track. Loaded cars run down to the wharf by gravity and

are drawn back to the quarry by cable. The wharf is equipped with a stiff-leg derrick, and the quarry with two derricks, necessary channeling and gadding machines, and a complete machine shop. The power plant near the quarry which operates the quarry derricks and the tramway cable is equipped with an 80-horsepower boiler. A small engine on the wharf operates the derrick there.

The character and relations of the marble deposit are described as follows by the Wrights,¹ who visited this locality while active work was in progress:

The extent of the marble deposit at this locality has been investigated at a number of points on the surface by open cuts and trenches and in depth by eighteen drill holes, and at all of these places marble usually of good quality is exposed. The marble belt is approximately 3,000 feet in width, striking in a northwesterly direction and dipping to the southwest. It is limited on the northeast by an intrusive granite mass and on the southwest by the shore line. To the south it crosses the entrance to Dry Pass, but just back of Shakan it is cut off by a granite mass, while to the northwest it extends into the channel and reappears at the entrance to Calder Bay, extending northward and overlying beds of conglomerate. Along the shore exposures and at the quarry small dikes of diabase, striking northeasterly and much altered and faulted, were observed intersecting the marble beds. Apparently these dikes antedate the metamorphism of the limestone and therefore the intrusion of the granite. They are, however, but a foot or two in width and not sufficiently numerous to affect the value or expense of quarrying the marble. In the present opening at the quarry only one dike is exposed. Both surface cracks and slipping planes are present in the surface exposures of the marble, but in depth these are less numerous and will not materially interfere with quarrying.

Three distinct varieties of marble are found—pure white, blue-veined with white background, and light blue, often having a mottled appearance. The pure white, which has a finely crystalline texture, is the most valuable. All of the marble is free from silica and flint beds common in most quarries and though thin seams of pyrite were observed they do not occur in a quantity detrimental to the stone. The following chemical analysis of the white marble was made by E. F. Lass for the Alaska Marble Co.:

Chemical analysis of white marble from Marble Creek, Prince of Wales Island, Alaska.

Insoluble matter.....	0
Oxide of iron (Fe_2O_3).....	Slight trace.
Sulphuric anhydride (SO_3).....	Trace.
Lime (CaO).....	55.59
Magnesia (MgO).....	.30
Carbon dioxide (CO_2).....	43.67
Undetermined .....	.44
	<hr/>
	100.00
Calcium carbonate (CaCO_3).....	99.28

A qualitative test for magnesia in a sample collected by the writers was made by Dr. George Steiger, of the United States Geological Survey, who reports a content of less than 1 per cent.

¹Wright, F. H. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 847, pp. 194-195, 1908.

To determine the crushing strength of the stone the Alaska Marble Co. submitted samples to N. H. Winchell, State geologist of Minnesota, who reports an average strength of 10,521 pounds per square inch, a strength ample for all building purposes. Though not equal to the best Italian grades this marble is better than most American marbles and in the market will compete on at least equal terms with the product of Vermont, Georgia, and Tennessee.

A thin section of the white marble from Calder, examined by T. N. Dale, showed a grain diameter of 0.075 to 0.625 millimeter, mostly 0.125 to 0.375. The Rosiwal measurements gave an average grain diameter of 0.0058 inch, or 0.147 millimeter. The grade is medium, and the texture is uneven.

A thin dike of metabasalt at this quarry contains much pyrite and a streak of pyrrhotite.

Experience in quarrying this marble seems to have shown that the whiter varieties are softer than the veined or clouded varieties. Areas in which the rock is too soft for commercial purposes are not uncommon, even in the depths of the quarry. The marble beds are much fractured, and as yet the fractures have not been found to disappear entirely with increasing depth. A vertical hole is reported to have been bored with a core drill 175 feet below the present bottom of the quarry, and two more holes were drilled in the southeast and southwest corners of the quarry for distances of about 200 feet at an angle of about 45° to the horizontal. All these cores are reported to have shown marble of good quality.

Shipments of marble were made from this quarry each year from 1906 to 1910, but no quarrying has been done since December, 1909. The product in rough blocks was shipped mostly to a sawing and polishing plant at Tacoma, Wash., where it was prepared for interior decoration. Shipments were also made to Spokane and San Francisco and to several eastern cities. The closing of the quarry may have been due to failure to find sufficiently hard stone within the depths quarried. According to recent reports, it is planned to reopen this quarry whenever the conditions of finance and the markets will warrant it. Some development work is reported to have been done at Calder in 1915, and some prospect drilling on Dry Pass near the Indian burying ground yielded good white cores. The equipment generally has been kept in good condition.

DRY PASS.

The marble area extends eastward from Calder about 2 miles along the north side of Dry Pass to a small shallow cove known locally as Winter Harbor, just east of the shallowest part of Dry Pass, where it terminates against a mass of gray granite. The marble in this vicinity is white and gray to light grayish blue in color and is coarsely crystalline near the contact with the granite. On the surface it is

not very hard and is easily disintegrated to sand by water running down the slopes. On the northeast shore of the small cove the marble forms low cliffs, over one of which, at the north end of the cove, falls a small mountain stream. Half a mile above the mouth of this creek a cliff of gray coarsely crystalline marble 100 feet high (No. 28) surmounts a talus slope about 200 feet high, which extends from the creek to the cliff. The top of the marble cliff is probably 500 feet above sea level. The general trend of the ridge is N. 60° E., and the marble mass may be continuous with the deposits located by the Vermont Marble Co. south of Red Bay. Between Winter Harbor and Shakan Bay the marble beds are cut by several dikes and are intruded by small areas of basaltic rock.

Thin sections of the white marble near the cove and of the light-gray marble from the cliff half a mile from the shore were examined by T. N. Dale. Both are coarse grained. In the white marble the grain diameter ranges between 0.56 and 4.48 millimeters, but mostly between 1.40 and 2.80 millimeters. Measurements according to the Rosiwal method showed an average grain diameter of 0.049 inch, or 1.24 millimeters, and the texture is fairly even. In the light-gray marble the grain diameter ranges between 0.28 and 2.80 millimeters, mostly 0.56 to 1.96 millimeters. The Rosiwal measurements showed an average grain diameter of 0.0331 inch or 0.84 millimeter, and the texture is uneven.

Marble as coarse as this seldom shows as great strength as fine-grained marble and is likely to show greater porosity and absorption, yet if normally sound stone can be obtained its strength will doubtless be found ample for all interior decorative work for which the marble would be suitable, and probably also for exterior walls of small buildings. Certain Georgia marbles that have been largely used for decorative purposes resemble the gray rock in color and texture.

EL CAPITAN.

On the north side of Dry Pass, about 2½ miles east of Winter Harbor, east of the granite mass just mentioned, marble beds (No. 29) form the surface rocks for a mile or more. Ten marble claims located here were acquired by the El Capitan Marble Co., in 1903. In 1904 a small quarry pit 12 feet deep was opened near tidewater by channeling and gadding machines, and 3 gangsaws operated by steam power were installed. A small quantity of marble was shipped to Seattle. Operations were suspended at the end of 1904 and have not been resumed, although the property has been cared for, and it is rumored that the quarry will be reopened. Drilling operations were under way in the summer of 1917.

The marble exposed in the El Capitan quarry is of medium grain and not very hard. It is of slightly coarser texture and shows more

contrast than the marble at Calder. The color is white with faint gray veins and cloudy areas. The exposures near the beach are badly fractured. In one set of fractures, which strikes N. 60° E., nearly all the openings are filled with quartz, which stands out in relief on the weathered surfaces. These quartz seams are nearly vertical and are spaced from 3 or 4 inches to many feet apart. A small geode of quartz crystals was noted in the marble exposed in the wall of the quarry pit. The presence of siliceous material in the marble may render the stone slightly difficult to saw uniformly. Several metadiabase dikes cut the marble beds. Near the quarry one dike which is much jointed and has been faulted and deformed ranges from 12 to 18 inches in thickness, strikes N. 40° E., and dips steeply southeast. Wright considers that the dikes were intruded and later disturbed, all, however, prior to the metamorphism of the limestone beds.

In the bluffs northeast of the El Capitan quarry at 200 to 400 feet above sea level are exposures of medium-grained light-blue marble which has been prospected by pits and trenches, and about half a mile above the mouth of a small creek that empties near the sawing plant are exposures of fine to medium grained white marble, all of which are included within the El Capitan group of claims.

Three thin sections of these marbles were examined by T. N. Dale. A section of the marble from the quarry opening showed an uneven texture and proved to have a grain diameter ranging from 0.05 to 0.75 millimeter, but mostly between 0.125 to 0.5 millimeter. Rosiwal measurements showed an average grain diameter of 0.0059 inch, or 0.15 millimeter. A section of the white marble exposed half a mile up the creek above the sawing plant showed a grain diameter of 0.05 to 0.5 millimeter, mostly from 0.07 to 0.25 millimeter, with an estimated average diameter of 0.125 millimeter, indicating that the grain is medium. The texture is even. A section of another specimen of white marble from the same deposit showed a grain diameter of 0.05 to 0.375 millimeter, mostly between 0.125 and 0.5 millimeter. The texture is uneven. Rosiwal measurements showed an average grain diameter of 0.0052 inch, or 0.132 millimeter.

KOSCIUSKO ISLAND.

On Kosciusko Island, on the opposite side of the channel from the El Capitan marble claims, are exposures of marble (No. 30), most of which is grayish, although some is nearly white. This marble is rather fine grained and is cut by fractures filled by siliceous seams like those on the El Capitan property. These seams are one-sixteenth to one-fourth inch thick, are spaced from 4 inches to 4 feet apart, strike N. 50° E., and are nearly vertical. According to practical

marble men the presence of quartz seams in such abundance as these renders the marble of very doubtful commercial value. Toward the east and south along this shore of Kosciusko Island the marble gradually merges into less metamorphosed limestone. At Aneskett Point the rock is a dense fine-grained limestone, much fractured and seamed with calcite.

In the eastern part of Kosciusko Island, between the southwest base of Pyramid Peak and the head of Tokeen Bay, three claims of 160 acres each (No. 31) have been located by the Vermont Marble Co. The marble here lies south of the granitic mass that is believed to have produced the metamorphism of the marble deposits of Calder and the El Capitan claim farther north. The deposit is exposed for about 200 feet in a steeply sloping bluff 20 to 30 feet high on the left bank of a small mountain creek that flows southwestward into Tokeen Bay about half a mile distant. At the lower end of the exposure the marble is dark bluish gray and fine grained, but the greater part of the deposit is medium grained and white and is thinly veined with dark-gray or yellowish seams. On the exposed face the marble is very soft and crumbly, almost saccharoidal, and it was difficult to obtain a sample firm enough to be carried away. The beds are cut by numerous joint planes. Prospecting has been done by blasting and by core drilling nearly at right angles to the face, which seems to represent a steep dip slope. The prospects are about 200 feet above sea level. To transport the marble to tidewater it would be necessary to build one-half to three-fourths of a mile of tramway through some rather rough country.

On the southeast shore of Kosciusko Island northeast of Edna Bay outcrops of dull to dark gray limestone alternate with narrow areas of graywacke for 2 miles or more. The limestone is cut by basaltic dikes and is everywhere badly cracked. At the contact with some dikes it is locally metamorphosed to marble, but the marble thus produced is probably not of uniform quality nor of sufficient extent to be of commercial value. On the shore 3 or 4 miles northeast of Edna Bay a small area of fine-grained red and white mottled limestone was noted, and a short distance inland, along a small stream (No. 32), occurs an area of fine-grained variegated marble in which stone of yellow, sienna, and red shades predominates. This is the same bed as the variegated limestone on the north side of Heceta Island (p. 76). Claims have been located in this area by W. C. Waters, of Wrangell, Alaska, and have been extensively prospected by the Vermont Marble Co.

A sample of brecciated fine-grained green limestone, seamed by veins of pink calcite, was sent to the Survey by W. C. Waters in the winter of 1915 from Kosciusko Island, "7 miles from Holbrook,"

probably in a southwest direction, which places it near locality 32. The green limestone is more or less mottled by dark and light green fragments, which, together with the pink veins, would probably produce a handsome effect in a polished surface. The rock shows slickensides, is very brittle, and breaks rather easily; therefore it might be difficult to work into large slabs. Mr. Waters states that the rock strikes northwest and extends over an area 100 by 300 feet; that the covering is moss, timber, and brush; and that the formations with which the green rock is associated are limestone and conglomerate.

Another interesting sample sent by Mr. Waters is a conglomerate of fine-grained light-gray limestone pebbles in a pink calcareous matrix cut by thin veins of yellowish calcite filling fault fissures. This rock is a little harder than the breccia described above and would undoubtedly polish well and produce a handsome effect. It is not known whether large blocks are available. The locality is given as Kosciusko Island, "6 miles from Holbrook," the observed extent of the material as 400 feet by a quarter of a mile, and the cover as moss, brush, and timber. The associated formation is reported to be limestone striking northwest.

MARBLE AND ORR ISLANDS.

GENERAL FEATURES.

The most extensive developments of marble in southeastern Alaska are in the northwestern part of Marble Island, one of the larger islands in Davidson Inlet, on which marble was first discovered in 1899. Quarrying has also been begun on Orr Island, just across the narrow inlet from Marble Island.

Marble Island extends about 3 miles from east to west and about 4 miles from north to south. Its surface is densely wooded and is generally of moderate relief, the highest point noted by the Coast and Geodetic Survey being 1,528 feet above sea level. According to the Wrights¹ the rocks of both Marble and Orr islands are classified as limestone and other sedimentary rocks, together with schists and volcanic tuffs, all of Paleozoic age. Much of the limestone in this area has been metamorphosed to a high-grade marble.

VERMONT MARBLE CO.'S PROPERTIES.

Certain marble claims that were located in the northwestern part of Marble Island in 1903 have been purchased by the Vermont Marble Co., which has opened large quarries (No. 33) and built a small village named Token. The total area held by the company aggregates 703½ acres, according to the plat of mineral survey

¹ Wright, F. E. and C. W., op. cit., pl. 1.



A. FOSSILIFEROUS BLUE-BLACK LIMESTONE BEDS IN TRAMWAY CUT 250 FEET FROM THE WHARF, TOKEEN.



B. STRIPPING OPERATIONS OF VERMONT MARBLE CO., SHOWING SURFACE OF WEATHERED MARBLE, TOKEEN.



**A. ANDESITE PORPHYRY DIKE ABOUT 1 FOOT THICK CUTTING MARBLE BEDS
ON WEST SIDE OF VERMONT MARBLE CO.'S QUARRY, TOKEEN.**



**B. FACE OF MARBLE AT DEPTH OF ABOUT 50 FEET IN VERMONT MARBLE CO.'S
QUARRY, TOKEEN.**

No. 927, made by L. D. Ryus, deputy mineral surveyor of Ketchikan. (See fig. 3.)

Blue-black limestone.—The marble in the main quarry is massive and has yielded no fossils except crinoid buttons, but it overlies thin-bedded blue-black limestone which has yielded fossils of probable Silurian age, consisting of *Merestina* sp., *Clorinda* sp., *Conocardium* sp., *Trochonema* sp., *Favosites* sp., and *Cyclonema* sp., as determined by Edwin Kirk, of the United States Geological Survey.

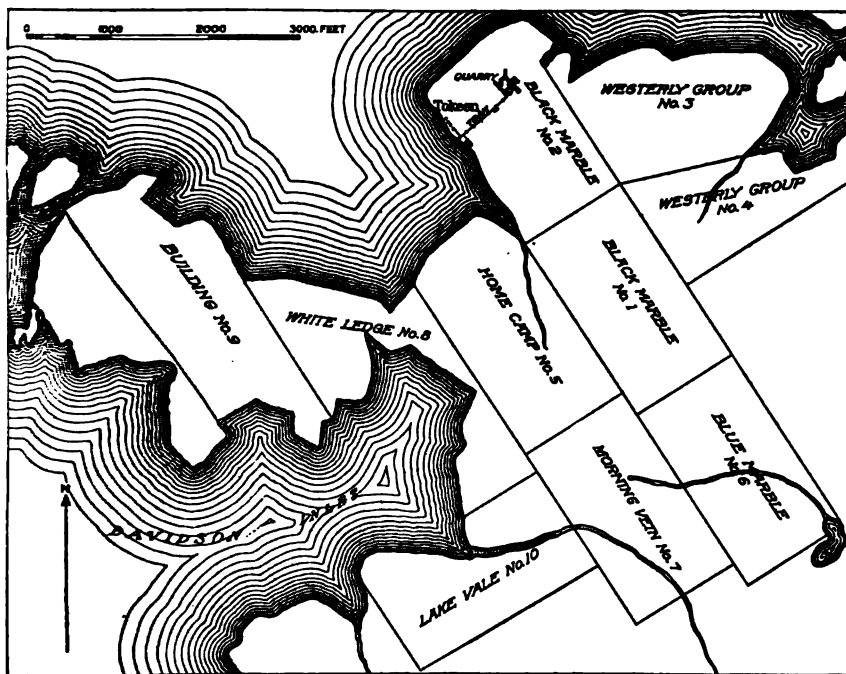


FIGURE 3.—Sketch map showing claims of Vermont Marble Co. on Marble Island.

Southwest from the Token wharf, along the shore of the island, an alternation of limestone beds, intrusive rocks, and marble occurs, but the blue-black limestone crops out around the cove in which the wharf is situated, and near the company's office a small area has been stripped and several blocks of the stone have been taken out. The rock is fine grained and dense but is much fractured and jointed. The openings have been cemented with white calcite. The beds range from 1 foot or less to 3 feet in thickness but on weathering separate into thin layers $1\frac{1}{2}$ to 5 inches thick. (See Pl. X, A.) The joints separate the rock in places into small blocks only 1 inch to 3 or 4 inches on an edge. The material takes a fine dark polish. (See Pl. VIII, B.) The rock is very brittle and breaks easily, not only along the calcite-filled joint cracks but also along the lamir

tions parallel to the bedding planes. Probably most of the surface material will have to be rejected, but at greater depth the joint cracks appear to become fewer and the rock tougher. The white calcite streaks that intersect the dark surface produce very attractive effects in the polished stone and it was expected that the material would be quarried and marketed as "black marble."

T. N. Dale examined a thin section of this blue-black limestone and found that it consists of calcite, mostly untwinned, measuring with the micrometer 0.009 to 0.094 millimeter, but mostly 0.02 to 0.047 millimeter, and averaging probably about 0.05 millimeter, and is therefore to be classified as of fine grain. The microscope reveals sparse minute opaque specks, probably carbonaceous material, and some cubes of pyrite.

The overburden consists of forest growth and decayed wood and mold $1\frac{1}{2}$ to 3 feet thick. The rocks dip 38° – 40° NE., and the edges of their tilted beds have been cut by solution into a very irregular surface. The tramway from the wharf to the marble quarry passes the opening on the blue-black limestone, so that the material can be handled with a minimum of expense.

White and veined marble.—Eastward from Token the blue-black limestone passes beneath the deposit of white marble, which extends to and probably far beyond a small bight on the north side of Marble Island, 400 feet from the quarry. The belt of marble and dark limestone is probably 2,500 feet or more in width, and it extends south-eastward into the interior of the island for a much greater distance—possibly entirely across to Orr Inlet. The color of the marble ranges from nearly white with dark-gray and black veins to light-gray and grayish-blue shades. The grain is medium fine and fairly uniform. The marble takes a good polish, and is said to resemble certain grades of Italian marble. Exceptionally grains of iron pyrites are present. The marble having dark veins on a white background is very much in demand at present for interior decoration. Blocks are sawed into slabs, which may be matched so as to form certain nearly symmetrical patterns. Such slabs have been used in a large number of buildings near the Pacific coast. (See "Uses of Alaska marble," pp. 110–112 and Pls. XVI (p. 78), XXIII (p. 92), XXIV (p. 93), and XXV (p. 94).)

Thin sections of the marble from Token were studied microscopically by T. N. Dale. A section of the white marble showed a grain diameter of 0.07 to 1.5 millimeters, mostly 0.52 to 0.2 millimeter, with an estimated average diameter of 0.31 millimeter, falling within the limits of medium grain. The texture is very uneven. One section is crossed by a band of very fine untwinned dolomite (?) along which shearing has taken place. (See Pl. VI, B.) A section of the veined white and gray marble, which showed a very uneven

texture, includes parts that are extremely fine and parts that are extremely coarse, but in most of the section the grain diameter ranges from 0.025 to 0.625 millimeter, mostly 0.1 to 0.375 millimeter. In the very coarse portions there are grains with a maximum diameter of 0.875 millimeter. The Rosiwal measurements gave an average grain diameter of 0.0051 inch, or 0.13 millimeter. The grade is therefore, in general, medium. The rock shows streaks of very fine, untwinned magnesian calcite grains with graphite. A large grain of pyrite 0.4 millimeter in diameter was noted.

The following determinations made by R. K. Bailey show that the veined marble contains considerable magnesia:

Analyses of white and veined marble from Tokeen.

	White.	Veined.
Insoluble matter	0.01	0.20
Calcium carbonate (CaCO_3)	99.51	81.90
Magnesium carbonate (MgCO_3) .....	.94	14.93

The marble appears to be wholly metamorphosed. The material is massive and shows no indication of its original bedding, but it is much jointed and fractured and within 10 to 20 feet of the surface is rather soft. The joint planes cut the deposit at many angles but may perhaps be referred to several systems, the two principal ones striking about N. 50° E. and N. 40° W. The dips of the joint planes are likewise at many angles, and the spacing of the joints is variable, ranging from a few inches to 10 feet or more. In some places parallel joints, or "headings," are rather close together, rendering it impossible to obtain blocks large enough for shipment, but elsewhere blocks 4 by 4 by 10 feet free from cracks may be easily obtained. Wedge-shaped blocks that are completely separated from the surrounding mass by smooth joint planes are occasionally encountered in quarrying. Near the northeast side of the main quarry the marble is cut by a dike of altered andesite porphyry, 8 to 16 inches thick, containing much pyrite and dipping 17°-25° NE. (See Pl. XI, A.)

The jointed structure of the marble is the most serious hindrance to its profitable exploitation. It is to be expected that joint cracks should be present at the surface and that surface water should descend along these cracks, enlarging them, softening the marble, and oxidizing it to a faint yellowish hue, but according to experience in many other regions it might be expected that at depths of 40 to 60 feet the joint cracks would disappear and the marble become solid. To the depth quarried in 1912 (60 feet), however, it showed joint cracks in places (Pl. XI, B), and it may be possible that the widespread volcanism to which the Pacific coast of northwestern North America

has been subjected has disturbed the rocks generally to much greater depths than in other marble-quarrying regions.

The white marble was also analyzed in the chemical laboratory of the Bureau of Standards, with the following results:

Chemical analysis of white marble from Token.

Iron oxide (Fe_2O_3)	Trace.
Alumina (Al_2O_3)	0.14
Lime (CaO)	55.80
Magnesia (MgO)	.47
Sulphur trioxide (SO_3)	Trace.
Loss	43.77
Carbon dioxide (CO_2)	43.86
Insoluble residue	.26
Hydrogen sulphide (H_2S)	Not detected.

Sample has 99.5 per cent CaCO_3 .

The following physical tests were made for the Geological Survey by the Bureau of Standards on a representative sample of the veined marble from Token. The compression tests show that this marble possesses slightly higher compressive strength than some of the best-known Vermont marbles.¹

Physical tests of marble from Token, Alaska.

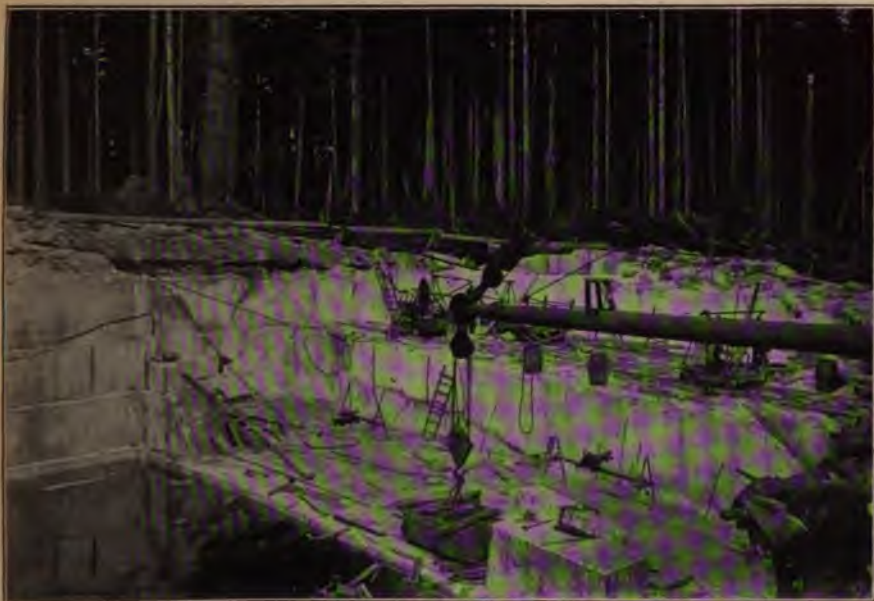
Compressive strength (pounds per square inch).		Absorption (per cent by weight).	Specific gravity.		Condition after 30 freezings.		Modulus of rupture on transverse test.
Dry.	Wet.		Apparent.	True.	Loss in weight (per cent).	Compressive strength (pounds per square inch). ^a	
12,894	12,532	0.104	2.715	2.720	0.02	13,598	1,556
14,547	12,843	.101	2.715	2.734	.02	13,481	1,822
14,452	15,097	.092	2.716	2.729	.02	12,628	1,748
12,255	12,196						
Av. 13,537	Av. 13,417	Av. .099	Av. 2.715	Av. 2.728		Av. 13,235	Av. 1,709

Porosity, 0.48.

^a Loss in compressive strength, 2.22 per cent.

Quarries.—The main quarry operated by the Vermont Marble Co. on Marble Island in 1912 is about 900 feet northeast of the shore of the small cove at the northwest corner of the island, at an altitude of about 15 feet above the wharf. In places bare knobs of marble are exposed in the vicinity of the quarry, but the surface of the marble, which is very irregular (Pl. X, B) as a result of solution and erosion, is generally covered by 1½ to 3 feet of decayed wood and mold. In places the roots of trees have followed the

¹ Marble from South Dorset: Average compressive strength per square inch, on bed, 11,300 pounds; on edge, 9,100 pounds. Marble from West Rutland: Compressive strength per square inch, "Extra dark blue," 13,689 pounds; "Rutland Italian," 14,068 pounds; "Rutland statuary," 11,525 pounds. Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, pp. 101, 121, 1912.



A. FIRST QUARRY OPENING, VERMONT MARBLE CO., TOKEEN.



B. WHARF AND WATER FRONT OF VERMONT MARBLE CO.'S PROPERTY, TOKEEN.

View shows derrick moving blocks of marble. The pile of rock in the water at the right of the wharf is waste marble.



U. S. GEOLOGICAL SURVEY

4. SOUTHWEST CORNER SHOWING STAIRWAY



B. LOWEST FLOOR.

VERMONT MARBLE CO.'S QUARRY. TOWN

crevices in the rock to depths of 5 or 6 feet. Trees and stumps are removed by derricks, and the soft mold by hand. The first small opening (Pl. XII, *A*) was abandoned at a depth of about 20 feet on account of several joint cracks 1 to 6 inches or more apart in the northwest end of the cut. These joints dip steeply toward the north, and the quarrying was shifted far enough northwest to avoid them for a time. This dip, however, brings them back into the quarried area at a depth of about 50 feet, and at 60 feet they are apparently about as numerous as at the surface.

In September, 1912, the top of the quarry opening measured roughly 90 by 100 feet, and the depth ranged from 10 to 60 feet. About one-half of the area had been quarried to the maximum depth. Methods of quarrying commonly in use at well-known marble quarries in the Eastern States are employed. (See Pl. XIII.) The equipment in the main quarry consisted of the necessary drills, seven Sullivan single channeling machines, four gadders and pumps, all operated by steam power generated by a 125-horsepower boiler near the quarry, and a complete machine shop. The blocks of marble are lifted from the quarry by a 25-ton derrick and are carried to the wharf (Pl. XII, *B*) on flat cars running on a standard-gage track. The loaded cars move by gravity and are drawn back to the quarry by a $\frac{1}{8}$ -inch steel cable. Waste rock is also trammed down to the wharf and dumped into the water alongside the pier. Deep water is reached by a pier about 150 feet long. A 25-ton stiff-leg derrick for unloading cars and loading marble on boats is operated by a small steam boiler on the shore near the wharf.

In September, 1912, a space of $1\frac{1}{2}$ acres about 375 feet southeast of the main quarry was being cleared for a new quarry. (See Pl. X, *B*.) The highest knobs of marble rise here to about 35 feet above the level of the wharf. The marble at this new opening is chiefly white with bluish-gray to black veins and clouds similar to that at the first quarry, but the deposit contains more dark-veined stone. One dike of meta-andesite $1\frac{1}{2}$ to 2 feet thick, striking N. 35° W. and dipping 78° SW., was noted. A full equipment had been installed, and in 1913 and 1914 active quarrying was carried on at this opening, two or three courses of stone having been removed. It is reported that below the surface, as far as quarried, the stone is fairly free from joints and fractures, and a good output of dark-veined marble seems assured.

About 60 men were employed in connection with this plant in 1912. The men live in sanitary and comfortable dormitories, eat excellent fare at a commodious mess hall, enjoy generally favorable conditions under which to work, and show a high degree of efficiency. Quarrying is carried on for eight months or more each year. The winters are not severe, and operations probably can be carried on throughout

most of the year when pipes from a reservoir are laid underground so that there shall be no danger of interruptions by freezing of the water supply.

Products.—Rough blocks 4 by 4 by 6 to 10 feet are shipped by freight steamers to the mill of the Vermont Marble Co., at Tacoma, Wash., where they are sawed, polished, turned, or planed for interior decoration. To save freight only perfect blocks are shipped, and therefore considerable material is wasted at the quarry. Some of the waste marble is trammed down to the wharf and used as filling. (See Pl. XII, B.) According to the absence or presence of joints the proportion of waste marble quarried may vary between 10 and 75 per cent. The marble for a foot or more on each side of most fractures is discolored and must be cut away. If a fracture crosses the block diagonally or near the middle, it may render the whole block worthless. If cheap power is developed, it might prove an economy to operate a small sawing plant at Tokeen in order to work the waste marble into slabs or building blocks.

Other prospects.—The Vermont Marble Co. has prospected claims about 1 mile and $1\frac{1}{2}$ miles south of Tokeen (No. 34). At one point a white marble of about the same texture as that at Tokeen, but somewhat shattered, is exposed in a small quarry at the base of a low bluff, where, it is reported, marble was obtained many years ago for making tombstones. The surface marble here has been softened by long exposure to atmospheric agencies, and none from any considerable depth was available.

At a second place several variegated marbles have been exposed by prospect pits. The most characteristic varieties are colored light to dark green, bluish, mottled light pink, and brownish gray. The mottled character is due to the presence of veins and nodules of fine-grained, dense calcareous material having a cherty appearance. The green varieties are veined with grayish green, darker than the body of the rock. The rock is massive and jointed and is cut by a thin dike of meta-andesite striking N. 40° W. The deposit was prospected by three or four drill holes, 60 to 94 feet deep, which showed that the green stone changed to gray or bluish within 15 to 25 feet from the surface. A small area was next stripped by hand, and two or three shallow pits were opened by a channeling machine, in the hope of developing a supply of desirable green marble. A wooden track on an incline was built from the test pits a short distance down to the water, in order to get out a few sample blocks of stone, and testing operations have been continued from time to time since 1912.

Between these two prospects there is a beach about 1,600 feet in length, along the greater part of which marble beds are exposed. The marble is veined and is white to grayish. It is cut by several meta-diorite dikes 8 inches to $2\frac{1}{2}$ feet thick, some of which are broken

and distorted. One dike noted had been faulted and offset horizontally a few feet, but the marble that filled the space between the broken ends of the dike showed only a flowage structure without a definite fault plane. The intrusion of the dike and the deformation of the beds through which it passes probably preceded the metamorphism that produced the marble.

Thin sections of two samples of the variegated marble from the deposit $1\frac{1}{2}$ miles south of Token were examined by Messrs. Dale and Loughlin. The brownish-gray cherty-appearing material is of very irregular texture. The grain diameter of the finer matrix, which consists of untwinned calcite, ranges from 0.025 to 0.075 millimeter, with an estimated average of 0.03 millimeter. The coarser calcitic part shows a grain diameter of 0.05 to 1.125 millimeters, mostly between 0.12 and 0.5, with an estimated average of 0.23 millimeter. Muscovite or phlogopite crystals reaching a length of 0.047 millimeter are widely disseminated. One grain of pyrite 0.7 millimeter in length was noted. A lens of dense dark granular material, cracked and veined with twinned calcite, appears in the section. The texture of the greenish marble was also found to be very irregular. The grain diameter of the finer matrix, most of which is probably untwinned calcite, is 0.02 to 0.12, most of the prominent grains ranging from 0.05 to 0.07, with an estimated average of 0.03 millimeter. The grain diameter of the coarser part, which is calcitic, ranges between 0.12 and 0.87 millimeter, with an estimated average of 0.24 millimeter. Much pyrite and a light-brownish mica (biotite) are present throughout the section, and some dark-grayish, very fine grained bands, cracked and veined with calcite, are prominent. These bands contain much fine epidote, scarce hornblende, and possibly some quartz and other silicate minerals not easily susceptible of recrystallization, indicating that the rock stretched and fractured and the relatively pure carbonate rock recrystallized and "flowed" into the stretch fractures.

The following determinations by R. K. Bailey indicate that there may be some cherty material in the brownish-gray rock:

Analyses of brownish-gray marble from deposit $1\frac{1}{2}$ miles south of Token.

	Brown rock.	Green rock.
Insoluble matter.....	20.77	7.82
Calcium carbonate (CaCO_3).....	78.65	91.70
Magnesium carbonate (MgCO_3).....	1.87	1.21

Limestone, slightly metamorphosed in places but generally a fine-grained bluish rock much fractured and seamed with calcite, alternating with graywacke, forms the coast line around most of the west and south sides of Marble Island. A considerable area of true

marble, however, occurs along the middle of the east side of the island and on the west side of Orr Island, which is separated by a narrow channel from Marble Island.

MISSION-ALASKA QUARRY CO.

A group of claims lying on both Marble and Orr islands (No. 35) and crossing Marble Passage, the channel between them, is under development by the Mission-Alaska Quarry Co., of San Francisco, Calif. On Marble Island rocks of two colors occur, one nearly white, the other grayish blue. The light-colored marble lies south of the blue marble and apparently overlies it, although the stratigraphic relations of the two are not wholly clear. A small bluff of white marble is exposed at the water's edge almost directly opposite the quarry on Orr Island. This marble is massive and of medium grain for 15 to 20 feet above the water. Higher up the slope the weathered surface shows thick layers, and the grain is somewhat finer. Only a little prospecting has been done here.

The blue marble crops out in a low swampy tract along the shore about half a mile northeast of the bluff of white marble. It is dense, hard, and fine grained and shows white calcite streaks along bedding and joint planes. It appears to be more nearly a true marble than the thin-bedded blue limestone at Tokeen, which it nevertheless resembles somewhat in character. Weathering has accentuated the bedded character of the rock along exposed edges. The dip of these beds is steep toward the northwest. A little prospecting and sampling have been done on this deposit in the way of assessment work.

A thin section of the blue marble examined by T. N. Dale appears to be composed of a fine-grained groundmass containing streaks of graphite and crossed by coarse veins. Micrometer measurements showed the groundmass to have a grain diameter ranging from 0.02 to 0.14 millimeter, but mostly between 0.03 and 0.094 millimeter, with an estimated average of 0.04 millimeter. The vein material showed a grain diameter of 0.1 to 1 millimeter, mostly 0.25 to 0.5 millimeter.

On the Orr Island portion of the property considerable prospecting and development have been done, affording better opportunity for inspection than on the Marble Island portion. In September, 1912, the timber had been cleared along the water front, and a space about 50 feet square had been stripped and opened for quarrying about 25 feet above high tide. (See Pl. XIV.) The overburden is similar to that at the quarries of the Vermont Marble Co. on Marble Island. The surface of the marble is much furrowed and pitted by solution, and joints and fractures from a few inches to several feet apart are numerous, but they seem to close up and to become fewer even at the slight depth reached by the quarry. The marble exposed is of mod-



MARBLE QUARRY OF MISSION-ALASKA QUARRY CO. JUST BEING OPENED ON ORR ISLAND.

erately coarse grain, with a cream-colored to bluish-white ground-mass veined with dark gray, and in places shows mottled effects. Near the surface the veins producing the mottling are oxidized to a brownish color. The appearance of the mottled stone suggests that it may have been derived from a conglomerate, the pebbles of which have been compressed in one direction and stretched in another during metamorphism. Both the veined and the mottled types of stone are handsome in the rough as well as when polished. (See Pl. XV, A.) The marble in the north side of the quarry is cut by a dike of andesite, somewhat altered and containing considerable pyrite. For most of its length the thickness of this dike ranges from 2 to 6 feet, but it thins abruptly and terminates in a few irregular branching veins only a fraction of an inch in thickness. This dike strikes about S. 20° E. and dips steeply northeast. A similar and approximately parallel dike was recognized at a prospect about 100 feet northeast of the quarry.

A thin section of the "Dark Mission" veined marble from this locality, examined by T. N. Dale and G. F. Loughlin, showed an abnormal and irregular texture. The stone is made up of coarse and fine grained parts; the very coarse calcite grains have curved twinning planes and an interesting double twinning, and the fine bands have been twinned in a different direction by a secondary movement. A little pyrite is present. The coarse part shows a grain diameter ranging from 0.185 to 4.44 millimeters, but mostly between 1.1 and 2.2 millimeters. The large grains have been strained and curved during shearing or mashing along their boundaries and the fine part shows granulation. (See Pl. XV, B.) The estimated average diameter is 0.89 millimeter and the grade is coarse. The grain diameter of the fine part ranged from 0.02 to 0.5 millimeter, mostly 0.125 to 0.25 millimeter, with an estimated average of 0.1 millimeter. A section of a mottled specimen of marble showed an irregular texture, with slightly elongate grains, and a few streaks of fine untwinned grains of calcite. Micrometer measurements of the grain diameter indicated a range from 0.05 to 1.25 millimeters, but mostly of medium grain, between 0.175 to 0.37 millimeter, with an estimated average of 0.25.

Tests by R. K. Bailey showed that both of these marbles are high in calcium carbonate and contain minor amounts of silica and magnesia:

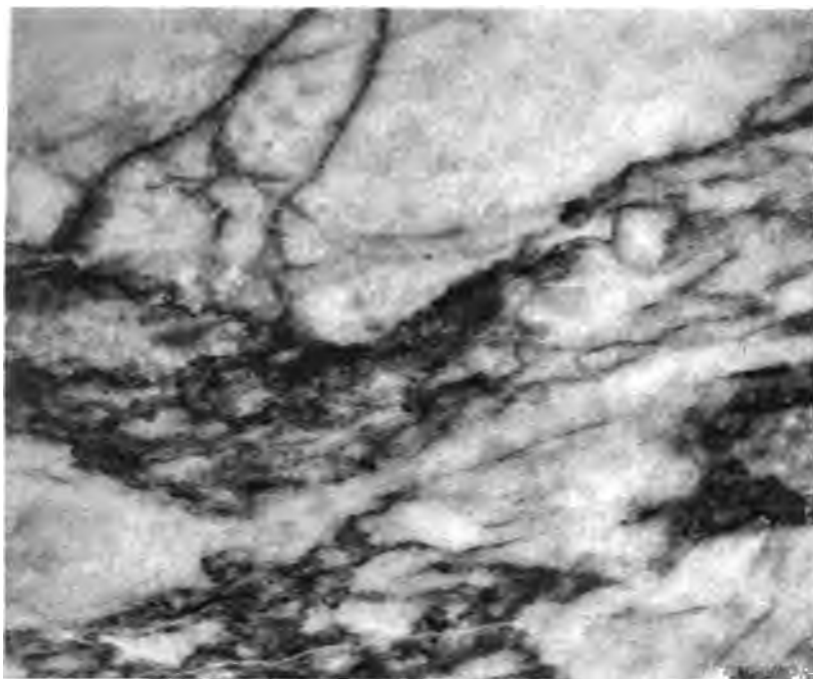
Analyses of marble from Orr Island.

	Dark veined.	Mottled.
Insoluble matter	3.50	2.95
Calcium carbonate (CaCO ₃)	95.99	95.35
Magnesium carbonate (MgCO ₃)	1.40	2.04

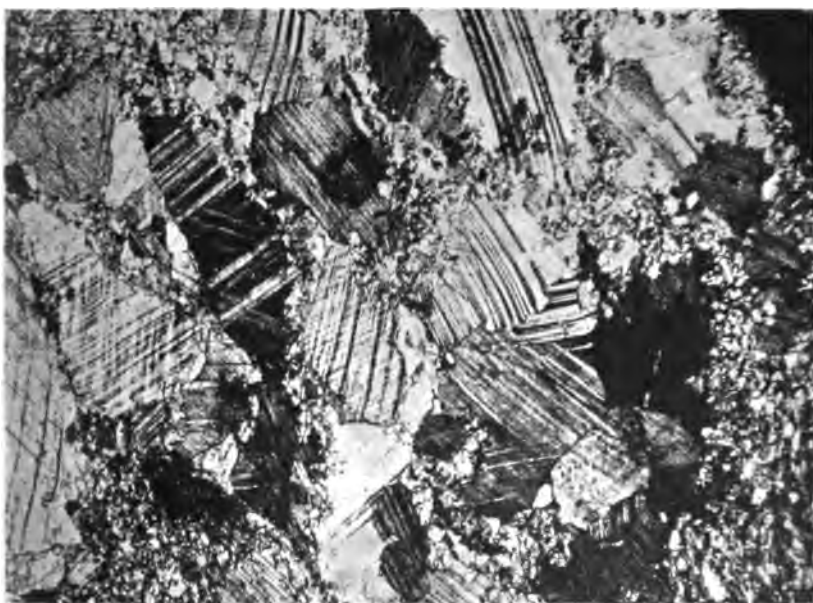
When visited in September, 1912, the quarry had been opened to a depth of about 11 feet only, and for the most part the surface rock had not yet been removed. Two drills and two channelers, both of the Ingersoll type, were in operation, and six or seven 10-ton blocks of marble from the second bench of the quarry were ready for shipment. The first consignment of blocks from this quarry reached San Francisco in February, 1913, and small shipments have been made in succeeding years. The quarry is equipped with hand-power derricks capable of lifting blocks weighing 10 to 15 tons. The marble will have to be carried by scows from the quarry southward about 1 mile and transferred to freighters in deep water. Marble crops out at intervals for several hundred feet along a low bluff parallel to the beach and has been shown to underlie the whole group of claims, but its depth and soundness had not been demonstrated by the drill when the writer visited the locality in 1912. It is reported that openings have since been made about 500 feet farther north and that the rock found was very satisfactory in quality, but that the beds show considerable fracturing. In 1914 progress was reported in testing by means of core drills at an angle of about 45°. In one vertical drill hole good marble more or less fractured was found to a depth of 99 feet.

HECETA AND NEIGHBORING ISLANDS.

In order to verify several reported occurrences of marble on Heceta, Tuxekan, and smaller neighboring islands practically all the remaining shores of Sea Otter Sound and Davidson Inlet, as well as parts of Tuxekan Passage and Tonowek Bay, were examined. The calcareous rocks bordering these shores proved to be for the most part nonmetamorphosed limestone, principally of the gray or blue fine-grained brittle type, with fractures filled with calcite. Near the middle of the north side of Heceta Island (No. 36) is an exceptional limestone colored pink, red, chocolate, green, yellow, and white, with mottled effects. The stone is fine grained, hard, and dense and takes an excellent polish. (See Pl. XVII.) Some of it is conglomeratic. It has been somewhat fractured and recemented with calcite, but it is only slightly metamorphosed, and it yielded a few fossils, among which were recognized *Conchidium* sp., *Capellinia* sp., *Trochonema* sp., *Heliolites* sp., and a pentameroid (?). These forms, according to Edwin Kirk, are of late Silurian age. This limestone crops out at the head of a small bay and was traced southeastward on the strike for about 300 yards and to an altitude of 50 feet or more above high tide. In places the colors are much paler, but the mottled character persists, and much of the stone is attractively colored. An area of graywacke borders this limestone on the west and north. The rock



A



B

A VEINED MARBLE ("DARK MISSION") FROM MISSION ALASKA QUARRY CO.'S PROPERTY, ORR ISLAND.

B PHOTOMICROGRAPH OF THIN SECTION OF VEINED "DARK MISSION" MARBLE FROM ORR ISLAND.

Shows the fine and coarse texture of the marble and the curved twinning planes of the coarser crystals.
Magnified 10 diameters.

is covered in most places by only a moderate thickness of moss and soil and supports the usual growth of brush and timber. Claims located on this mottled limestone by W. C. Waters are reported to have been sold to the Vermont Marble Co. in 1914. No marble was found on the smaller islands within this area—Cap, Hoot, Owl, Eagle, White Cliff, and Green islands.

An analysis of a sample of this mottled limestone by R. K. Bailey showed considerable insoluble material, probably mostly silica and iron oxide:

Analysis of mottled limestone from Heceta Island.

Insoluble matter.....	13. 18
Calcium carbonate (CaCO_3).....	84. 46
Magnesium carbonate (MgCO_3).....	2. 85

DALL ISLAND.

WATERFALL BAY.

Samples of marble obtained near Waterfall Bay (No. 37), on the west coast of Dall Island, were shown to the writer at Ketchikan by M. D. Ickis in 1912 and found to be of much merit. The principal colors are white, pink, gray, and blue-black. The white and pink varieties are very handsome, the pink occurring in various delicate shades and in areas mottled with white. Some of the white marble is veined with yellow. Green marble is reported to occur but has not been much prospected. The white and pink varieties appear to have been wholly metamorphosed, but the gray and blue varieties appear to possess the characteristics of little-altered limestone. The grain of all the samples is fine, that of the gray and blue varieties exceedingly fine. In the lighter-colored varieties calcite crystals larger than the average are exceptionally present, but in general the texture is uniform, and thin pieces of the stone are as translucent as alabaster. This marble takes a very high polish. (See Pls. XVIII and XIX, A.)

These marble deposits, which were not visited by the writer, lie about the head of Waterfall Bay, near the middle of the west coast of Dall Island. Twenty claims in all, aggregating 400 acres, have been located under the names Eurus, Marble Heart, St. Augustine, and Marble Bay groups. Openings are reported to have been made on a steep hillside about 300 feet above tide level and about 1,000 feet from the beach. Assessment work is said to have been done on these claims as late as 1915. A few dikes of "trap" rock 1 foot to 4 feet wide are reported to cut the blue marble beds. The rock is probably much jointed, as many of the samples shown to the writer displayed one or more smooth joint faces. Blocks of the pink marble only 2 to 3 inches wide have been produced by parallel

joints. It is said by interested parties that enough marble is available in these claims to warrant development and that several thousand dollars has been expended in prospecting, but emphasis should be given to the often repeated caution that the regional disturbances are likely to have badly shattered this marble.

Theodore Chapin, of the United States Geological Survey, visited the Waterfall Bay region in the summer of 1915, and as a result of his observations contributes the following notes on the geologic relations of these marble beds:

The geology of the region is simple. South of the bay the rock is limestone. The dominant color is blue to black, with lighter-colored areas where mar-marized. Overlying the limestone with apparent conformity is schistose greenstone containing conglomerate beds, occupying the north shore of the bay. The contact extends about N. 75° E. from the cabin at the head of the bay. Both limestone and green beds stand nearly vertical but dip northwest at high angles except where overturned. The best marble noted occupies a belt of varying width along the greenstone contact. At one locality marble crops out to a measurable width of 400 feet, besides a considerable thickness of semicrystalline limestone. The marble has been exposed by surface stripping for several hundred feet from the head of the bay. At 300 feet from the cabin, at an altitude of 220 feet, the following section is exposed:

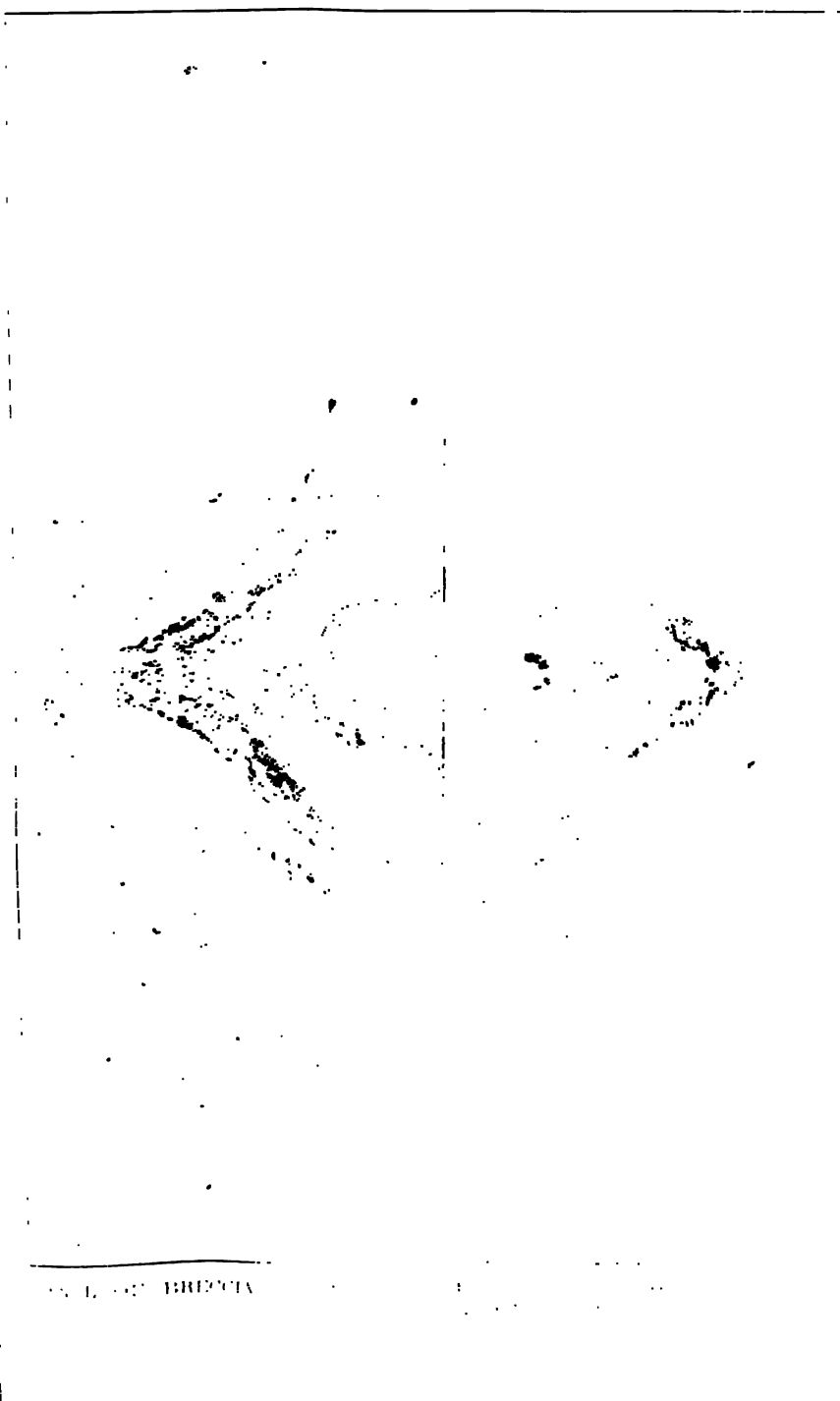
Section of marble on Waterfall Bay 300 feet from cabin.

	Feet.
Greenstone.	
Bluish-gray marble crops out only at intervals.....	300
Blue and white mottled marble.....	4
Dike.....	$\frac{1}{2}$
Thin-bedded white marble with black specks and white mica..	4
Pink-mottled white marble.....	13
Blue and white mottled marble, exposed.....	25±
Base concealed.	

The best commercial marble in this section is the 13-foot bed of pink-mottled white marble. The upper and lower parts of the bed are even-textured, medium to fine grained white marble mottled with a very delicate pink tint and veined with irregular threadlike veinlets of yellow. In the central part of the bed the pink color is more pronounced and the rock contains much white mica, a combination that produces a handsome rock. A short distance beyond this locality the following section is exposed:

Section of marble on Waterfall Bay 600 feet from cabin, at an altitude of 400 feet.

	Feet.
Schistose greenstone.	
Bluish-gray marble (in part mottled and veined with black)...	300
Fine-grained white marble with brown veinlets carrying mica and pyrite.....	26
White marble with green patches and brown veinlets.....	7
Fine-grained white marble with brown and green veinlets carrying mica and pyrite, contains a few large crystals of calcite	9
White and pink marble with green areas.....	11



	Feet.
Fine-grained white marble with pyrite in tiny veinlets and disseminated in particles.....	16
Quartz schist containing pyrite.....	1
White marble, with pyrite and much chlorite in tiny stringers and veinlets.....	10
Dike.....	2
Concealed.....	15
Blue limestone, with beds of white marble and schistose beds, grading downward into fossiliferous limestone.	

The white and pink marble with mottled-green areas is very handsome and susceptible of a high polish, except where the green minerals predominate. The greater part of the bed is white and pink marble, composed of nearly pure calcite of very fine grain, the individual minerals averaging about 0.05 millimeter in diameter. The base and top of the bed are variegated with green areas, which, combined with the pink-mottled white rock, give a very striking effect. Under the microscope the green areas are seen to consist of sericite, quartz, and chlorite; the white and pink rock is essentially calcite. The great thickness of bluish-gray marble at the top of the measured sections contains beds of ornamental marble of commercial value. These beds are black and white, mottled in very intricate pattern, and bluish white with black veinlets. This rock takes a smooth polish.

Marble crops out at several places along the south shore of the bay between the cabin and the greenstone contact. Near the cabin an opening has been made on a bed of fine-grained, even-textured white marble, carrying flakes of white mica. Another commercial marble on this bay is a fine-grained black variety that takes a good polish. The polished surface shows a black field with white-mottled areas and irregular veinlets of white calcite, which give it a pleasing appearance.

Two specimens of the marble from Dall Island were examined by T. N. Dale and G. F. Loughlin. A section of the white variety was found to consist of plates of fine-grained twinned calcite in a matrix of extra-fine, untwinned grains of calcite. The general texture of this marble resembles that of a marble from the Huntley quarry at Leicester Junction, Vt., which has an uneven parallel elongate texture with alternate irregular tiers of large and small grains,¹ called "flaser" structure, but the marble from Dall Island is less regular. The twinned calcite plates range in diameter from 0.075 to 0.375 millimeter but mostly from 0.125 to 0.25 millimeter, and would be considered of medium grain. The grain diameter of the matrix material is fine, measuring from 0.009 to 0.037 millimeter. (See Pl. XVIII, B.)

The other specimen consisted of fine-grained, considerably fractured stone, having a gray groundmass containing a few irregular reddish mottlings and several white and yellow streaks along fracture planes, also some granular calcite filling former openings along fracture planes. The section showed an extra fine grained ground-

¹ Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 21, pp. 147-148, fig. 25, 1912.

	Feet.
Fine-grained white marble with pyrite in tiny veinlets and disseminated in particles.....	16
Quartz schist containing pyrite.....	1
White marble, with pyrite and much chlorite in tiny stringers and veinlets.....	10
Dike.....	2
Concealed.....	15
Blue limestone, with beds of white marble and schistose beds, grading downward into fossiliferous limestone.	

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¹ Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, pp. 147-148, fig. 25, 1912.

mass crossed by a band 0.66 millimeter wide, faulted transversely, consisting of calcite plates 0.094 to 0.56 millimeter in diameter. The groundmass shows a grain diameter ranging from 0.02 to 0.14 millimeter, but mostly from 0.037 to 0.076 millimeter. The estimated average diameter is 0.04 millimeter, and the grade is fine.

An analysis of the white marble by R. K. Bailey gave the following percentages:

Analysis of white marble from deposit near Waterfall Bay, Dall Island.

Insoluble matter-----	0.32
Calcium carbonate (CaCO_3)-----	99.59
Magnesium carbonate (MgCO_3)-----	1.03

BREEZY BAY.

In the autumn of 1914 and early in 1915 W. C. Waters examined the east shore of Dall Island and portions of Long Island and sent to the Survey samples of limestone and marble collected from several localities in these areas.

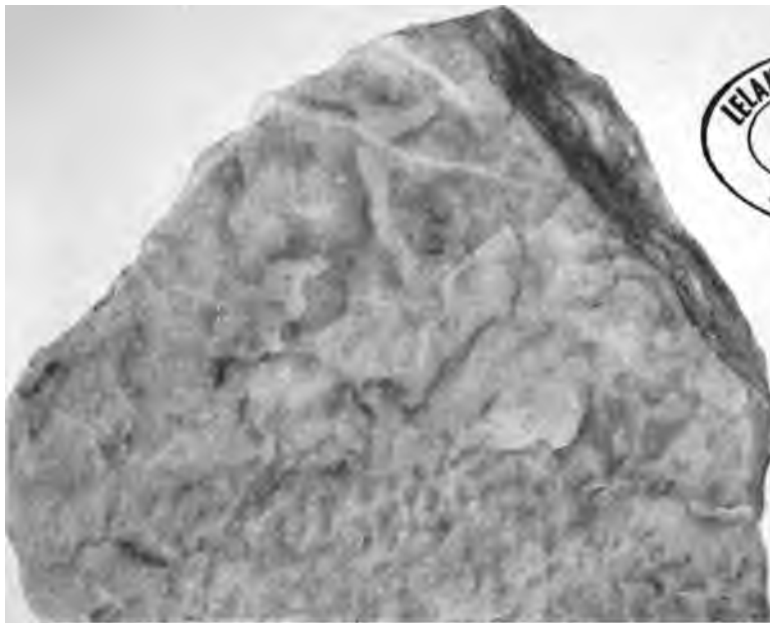
Mr. Waters's notes show two narrow areas of marble striking in a westerly direction from the northern part of Breezy Bay (No. 38) and an area of limestone a short distance to the south of the marble. The color of the sample of marble from Breezy Bay is uniformly light gray, and the texture is generally fine grained and dense as seen under a field lens. The rock is evidently composed mainly of calcium carbonate. The ledge is reported to be about 100 feet wide and to stand nearly vertical, with a west-southwest strike. So far as explored there was little cover besides moss over the ledge.

VIEW COVE.

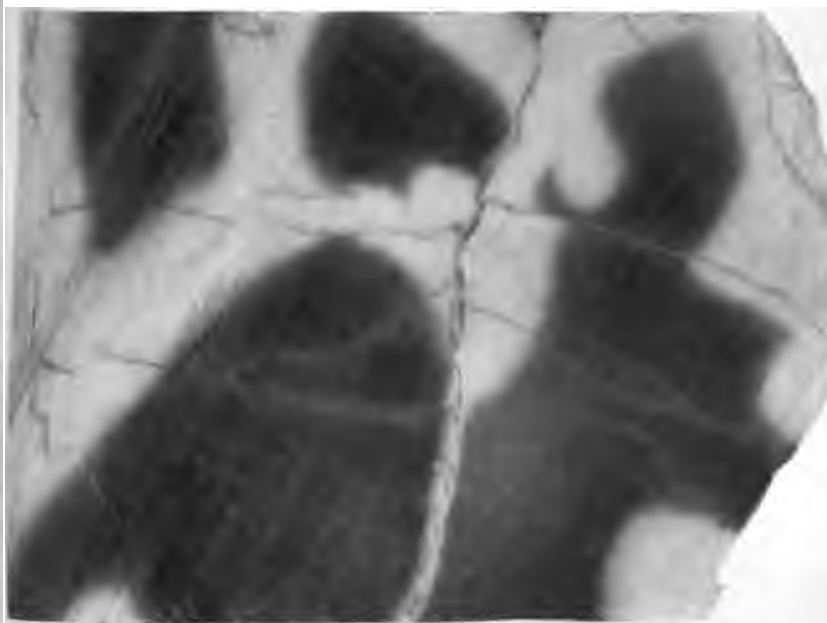
Mr. Chapin also visited certain portions of the east coast of Dall Island. With regard to a deposit near View Cove (No. 39) he furnishes the following notes:

Marble deposits occur on the east coast of Dall Island at a number of places. Near the head of View Cove a stream that enters from the southwest flows in a gorge following joint planes in the marble. This stream was traversed from the beach for half a mile and in that distance the beds strike about north-west, directly across the course of the stream, and stand nearly vertical. Most of the marble seen is pearl to gray in color and mottled and veined with white. At one locality occurs a 4-foot band of yellow marble with a green stripe, and bordering it is white marble mottled with yellow. The yellow marble takes a good polish and has a warm, soft tone. Associated with these beds is a little bluish-black marble. A polished specimen shows a black field variegated with dark-gray areas and tiny veinlets of white calcite.

Mr. Waters also reports that several colored varieties of marble occur here, including white, pearl, light with black veining, black, green, and yellow, and has sent samples of the pearl-colored, gray-



A



B

A. FINELY MOTTLED LIMESTONE FROM NORTHERN PART OF HECETA ISLAND.

B. COARSELY MOTTLED LIMESTONE FROM NORTHERN PART OF HECETA ISLAND.

veined, yellow, green, and black varieties to the Survey. The pearl-colored rock, in the hand sample, gives brisk effervescence with hydrochloric acid and is uniformly fine grained and dense, except for a few thin streaks of crystalline calcite. The color is not uniform but shows gradations from pearl to gray. A few small specks of pyrite were noted along a fracture plane. A thin section of this marble was examined by G. F. Loughlin, who reports that the material shown is nearly all even-grained calcite with a few large grains (single or aggregates) as much as 2 millimeters in diameter. The fine grains range from 0.01 to 0.3 millimeter in diameter and average about 0.08 millimeter. The grade of texture is therefore fine. A very few minute black grains, some certainly of pyrite, were noted; the largest was 0.035 millimeter in diameter. A few flakes of graphite may be included. The section also shows a very few grains of quartz 0.03 or 0.04 millimeter in diameter.

The gray-veined material consists of medium-grained calcite with veins and spots of darker-gray finer-grained material showing close-folded structure. If large slabs of this marble could be obtained the effect, after polishing, would be very handsome.

The black marble is bluish-black in the unpolished sample. It is a fine-grained, dense high-calcium limestone, possessing the color and density characteristic of rocks that are susceptible of high polish and that show a deep black color on polished surfaces. The rock is brittle and shows fine fractures recemented with calcite, and for this reason it is probably questionable whether large thin slabs could be prepared from it.

The yellow sample (see Pl. XIX, *B*) is generally fine-grained, dense high-calcium marble. It takes a high polish, which brings out well the color, a warm light brownish yellow that resembles the yellow areas in the Italian Siena marble. This color in the hand sample, which is $3\frac{1}{2}$ by 4 inches, is not uniform but becomes slightly lighter toward one edge. This is a very handsome marble, and if it can be obtained in large quantities and the conditions for quarrying and transportation are favorable, the deposit should prove to be very valuable.

The green marble is also fine grained, and consists mostly of calcite but carries dark streaks of micaceous carbonaceous material with considerable pyrite. The general effect in the hand sample is grayish with clouded areas of grayish green, streaks of black, and here and there mottlings of light gray, giving altogether a very attractive appearance. The rock takes a high polish except along the black streaks, which consist of material harder than calcite.

The marble in the vicinity of View Cove is all of the calcite variety.

COCO HARBOR.

Marble is reported to occur on the north shore and limestone on the south shore of Coco Harbor (No. 40). From W. C. Waters's notes it is inferred that the beds strike west-northwest and dip south and that large dikes of "greenstone" cut the beds at intervals of 30 to 40 feet, with small dikes between.

Mr. Chapin also noted the marble on the northwest side of Coco Harbor half a mile from the head. He writes in regard to it:

Where it crops out along the beach it is evidently faulted against gray limestone. Back from the beach the outcrops are too few to determine its relations accurately. The marble is white to gray. Much of it is very fine grained and pure white, and portions of it are coarsely crystalline with large flashing crystals of calcite. Pyrite is not abundant but was noted in places as veinlets and disseminated particles.

A sample of fine-grained white calcite marble was sent to the Survey from this locality by Mr. Waters. It appears to be of good white color but is a little soft and resembles the marble on the shore of Hood Bay, Admiralty Island (p. 54), examined by the writer. It is reported to contain so much iron oxide in places as to be of doubtful value. The ledge is said to be about 200 feet wide and to be covered mainly by 2 to 3 feet of earth, moss, and roots.

BALDY BAY.

At High Point, on Baldy Bay (No. 41), marble was noted by Mr. Waters, who reports a ledge about 200 feet wide consisting of fine-grained white material, very much fractured on the surface. The ledge strikes west where noted, but the rocks in this locality are very much disturbed and dip and strike in many directions. Samples sent to the Survey are grayish to yellowish white and also bluish-gray medium-grained calcite marble containing in places grains of pyrite. The rock is of medium hardness. The marble beds are associated with slate.

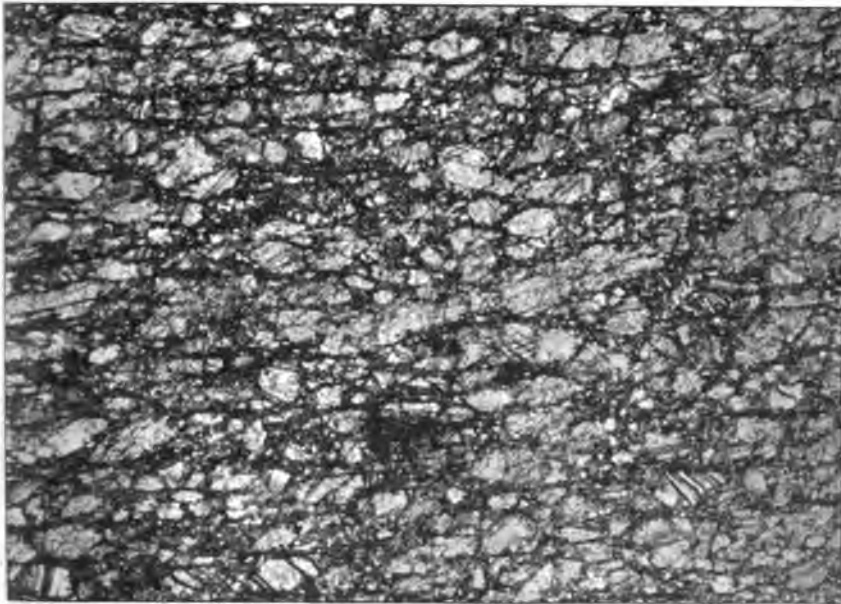
GRACE HARBOR.

A bed of white marble 6 or 8 to 20 feet wide having an easterly strike was noted by Mr. Waters half a mile south of the entrance to Grace Harbor (No. 42). Samples sent to the Survey are fine grained, dense, and very hard. The color is white, but some of the rock shows clouds of a faint brownish-yellow color.

AMERICAN BAY.

A deposit of schistose marble on the south side of American Bay (No. 43) is reported by Mr. Waters. The deposit is more than 500 yards wide, stands about vertical, strikes east, and is mostly covered by moss and timber. The marble is reported to be both fine and

4



B

1. FINE-GRAINED PINK AND WHITE MOTTLED MARBLE FROM WATERFALL BAY, DALL ISLAND.
2. PHOTOMICROGRAPH OF THIN SECTION OF FINE-GRAINED WHITE MARBLE FROM WATERFALL BAY, DALL ISLAND.

Shows parallel elongate or "blaser" structure, consisting of alternate irregular tiers of fine and still finer grains, the small grains in places forming borders about the edges of the larger grains. Some of the larger grains are twinned. Magnified 25 diameters.

coarse grained and to contain mica, but no mention is made of its color, and although a sample was sent it did not reach Washington.

Limestone and marble are also reported in the vicinity of Kaigani Harbor, but no descriptive details are available.

CAPE MUZON.

A bed of schistose marble 10 to 100 feet wide and 2 miles long "in the vicinity of Cape Muzon" is reported by Mr. Waters, who notes that the bed strikes west and stands nearly vertical. The material is reported to be white, pink, and green. A sample received by the Survey is of brownish-pink color, medium grain, and bright appearance. From notes on a chart sent by Mr. Waters it appears probable that this marble crops out west of McLeod Bay (No. 44).

LONG ISLAND.

The northern part of Long Island appears to contain promising areas of marble. This part of the island is largely surfaced by calcareous rock. Theodore Chapin, who visited this locality in the summer of 1915, reports as follows:

Deposits of marble have recently been located near the northwest end of Long Island, 3 to 4 miles north of Howkan, on two small bays known locally as Waters and Gotsongni bays. At this locality the brush is very thick along the shore and outcrops are few, making prospecting difficult, but physical conditions favor the exploitation of the deposits. The shore of the island rises abruptly from the beach, the timber is plentiful and of an exceptionally good grade, and the deposits occur on sheltered harbors which afford easy access to boats.

On Waters Bay three claims, the Lily, Long Island, and White Cloud, have been located, and assessment work has been done. Most of the marble exposed has a bluish-white field with white-mottled areas and blue-black stripes. Under the microscope the rock is seen to be composed essentially of twinned calcite crystals ranging in size from 0.25 to 0.7 millimeter, inclosed in a network of finely granular calcite that averages about 0.05 millimeter and forms with the large calcite crystals an intersertal fabric. The large calcite crystals are bent and fractured. They are evidently crushed fragments around which the fine-grained calcite has recrystallized. The black stripes are composed of opaque particles of carbonaceous material, probably graphite. Associated with the striped marble are beds of medium-grained white marble of even texture and also beds of blue-clouded white marble with yellow patches. This rock takes an excellent polish.

The deposit at the head of Waters Bay (No. 45) is reported by Mr. Waters to strike northwest and to extend up both sides of a small stream for a distance of a mile, with a width of 2,000 feet. Samples of white, pearl-gray, gray-banded, and gray-veined marble from this locality were received at the office of the Geological Survey. The white marble is medium grained and shows faint pinkish-yellow tints. The hand sample is of granular texture, shows a bright, spark-

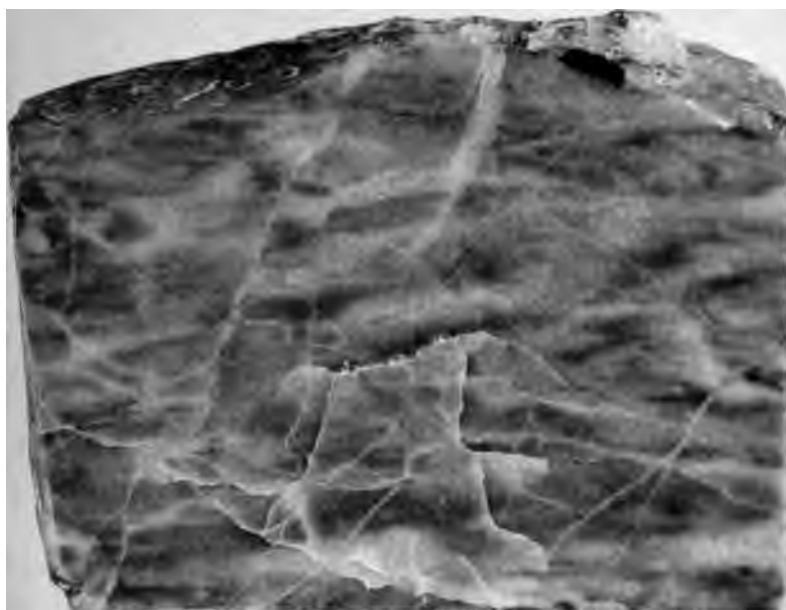
ling surface, and is translucent on thin edges. When struck it gives a clear ring.

A thin section of the pearl-gray marble was examined by G. F. Loughlin. The material as seen under the microscope appears to be rather even-grained calcite, mostly twinned, with fine granulated borders. The grain diameters range from 0.08 to 0.7 millimeter and average between 0.20 and 0.25 millimeter, as the coarser grains predominate. The grade is, in general, medium. A few very fine oxidized pyrite grains scattered through the section were noted. The largest of these is only 0.04 or 0.05 millimeter in diameter. The section shows several minute limonite pseudomorphs after pyrite, also a few streaks of limonite, sufficient to give a pale-brown streak across a hand sample of the marble. A shear zone, containing rounded grains and a few very fine grains of quartz in a matrix of pulverized calcite, was noted. No quartz was seen elsewhere in the section. So far as the material in the thin section is concerned, oxidation is practically completed and no further staining from pyrite is likely. In fact, pyrite is so rare in the sample as to cause a negligible amount of staining.

The banded marble is similar in texture to the white marble but has a light-gray body with parallel straight thin bands of darker gray spaced one-eighth to one-half inch apart. The veined marble is similarly colored but less uniformly grained. The veins and clouded areas show attractive patterns produced by folding of the rock. It is reported that this deposit appears to be "solid"—that is, comparatively free from fractures and joints.

According to Messrs. Chapin and Waters there is at the northwest corner of Long Island, on the east side of Gotsongni Bay about three-quarters of a mile from the head of the bay (No. 46), an exposure of marble half a mile in length. The beds appear to strike north-northwest, or parallel with the axis of the bay. On the beach are outcrops of coarse-grained even-textured white marble. A short distance back from the beach and separated from the white marble by a brush-concealed strip is a large area of bluish-white to bluish-gray marble with black stripes. The rock is medium grained and even textured. It takes a good polish and is apparently free from quartz. White and pink varieties of marble are also reported to occur in this locality.

A sample of the white marble sent to Washington by Mr. Waters is medium-grained calcitic material with a bright, sparkling surface where freshly broken. The rock possesses a high degree of translucence. A thin section of this marble was examined under the microscope by G. F. Loughlin. The material is composed of large



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- A FINEGRAINED GRAY AND VARIEGATED MARBLE FROM WATERFALL BAY, DALL ISLAND.
B YELLOW MARBLE FROM VIEW COVE, DALL ISLAND.

irregular grains separated by a network of fine grains. This texture is due to granulation along the boundaries of the crystals and has been termed "flaser" structure. (See p. 79.) The diameter of the interstitial grains is 0.02 to 0.10 millimeter with an average of about 0.04 millimeter. The coarser grains are 0.02 to 2.6 millimeters across and average about 0.06 millimeter. The average grain diameter of the marble, according to Mr. Chapin, is 0.25 millimeter. The only impurities noted by Mr. Loughlin were a cluster of pyrite (?) grains about 0.14 millimeter across and one very minute crystal of quartz (?).

A sample of the pink marble consists of medium to coarse grained crystalline calcite, of a salmon-pink shade. The rock takes a good polish, and the polished surface brings out slight variations in the pink color and also several streaks of colorless calcite.

An area of marble at Howkan is shown on Mr. Waters's field map, but no notes concerning it are available.

SOUTHEASTERN PART OF PRINCE OF WALES ISLAND.

DOLOMI.

Certain marble deposits on the east side of Prince of Wales Island in the vicinity of Dolomi were described by the Wrights,¹ and as no new work was reported to have been done on the claims, they were not visited by the writer. The notes originally published are given below.

The properties of the American Coral Marble Co. are located at two localities—at the head of North Arm [47], where 12 claims have been located along the north shore of the inlet, and at the north entrance to Johnson Inlet [48], where the company has several claims extending from Dolomi eastward to Clarence Strait. The principal developments have been made at the North Arm property, and at this point a post office named Baldwin has been established. Active work at this locality began in 1904, and the marble deposits were prospected during that year. In 1905 a wharf was built, machinery installed, and buildings erected preparatory to quarrying the marble. During 1906, however, practically no work was done, and all of the machinery was removed in 1907. At the Dolomi property a small quarry was started on the hillside, at a point a quarter of a mile northeast of Dolomi post office and a few hundred feet from tidewater on the Clarence Strait side, and buildings were erected. No operations were in progress at these localities during 1907 [and none has been reported up to 1916].

The deposits at North Arm and at Dolomi consist of marble beds interstratified with chloritic and calcareous schists, striking northwest with steep dips, usually southwest. The surrounding area is mantled by a dense growth of vegetation, and the limits of the deposits have not been definitely determined, though where the marble is exposed it is much fractured, variable in color and composition, and intersected by a few narrow dikes of diabase. The fracture planes were probably formed principally during the period of tilting and folding of the beds and existed before erosion exposed the present surface outcrops.

¹ Wright, F. E. and C. W., op. cit., pp. 196-197.

Since that time weathering has accentuated and to some extent increased the number of fracture planes, and it seems probable, however, that in depth these planes, although potentially present as lines of weakness, will become less numerous and will not interfere greatly in quarrying.

Although some parts of the deposits consist of pure-white fine-grained marble of excellent quality, other parts are poorly colored, coarse grained, and of little commercial value, and it will probably be difficult to obtain large quantities of uniform grade. The better grade is reported to give the following analysis: Calcium carbonate, 94 per cent; alumina, 3.9 per cent; silica, 1.4 per cent; magnesia, 0.7 per cent. Pyrite is also present in small amounts, occurring in the seams and finely disseminated in some of the marble.

DICKMAN BAY.

Location.—An area of particular interest on account of the large variety of marble which it affords lies in the southeastern part of Prince of Wales Island, in the peninsula between Dickman Bay (named on Coast and Geodetic Survey chart 8100) and the unnamed narrow inlet to the north, here designated Shamrock Inlet (No. 49). Dickman Bay is an extension of West Arm of Moira Sound, and the area lies 11 to 12 miles southwest of Dolomi. According to a booklet published in 1913 by the owners, the Alaska Shamrock Marble Co., of Portland, Oreg., two groups of claims have been located—group 1, consisting of eight claims (United States Mineral Survey No. 946), and group 2, consisting of four claims (United States Mineral Survey No. 947), together aggregating 228 acres.

Relations and character of the marble.—The marble occurs in beds of varying thickness which strike N. 30°–40° W. and dip steeply southwest. It is interstratified with graywacke and schistose beds and intersected by dikes of diabase and basaltic rock. A small area of dark-gray granitic rock is exposed at the southeast point of the peninsula and appears to be in contact with the marble mass. The marble is more or less schistose in places, especially near the contacts of schistose beds, and it is banded locally near the contacts of dikes by the interlamination of marble and dike rock in layers ranging from less than 1 inch to several inches in thickness. Ledges of marble 20 to 75 feet wide alternate with areas of graywacke 50 to 1,000 feet across and have been traced in the direction of the strike for a mile or more. The surface exposures show more or less jointing and fracturing of the beds.

The surface of the peninsula north of Dickman Bay is rough and wooded. The banks generally rise abruptly from deep water, and the highest marble ledges reach an altitude of 350 to 500 feet above sea level at a few hundred feet from the shore.

Most of the marble on the Alaska-Shamrock claims is of fine grain, although in a few places some very coarsely crystalline material was noted. Numerous samples sent from the prospects to Portland,

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Oreg., have been polished and have revealed a large variety of colors in a great many combinations. As a rule the rocks take a good polish. The veins which produce the beautiful effects in the strongly veined or schistose marble do not take so uniform a polish as the calcite portions of the stone. The inequalities in the polish are due to the presence in the veins of minerals of varying degrees of hardness, such as quartz, mica, and chloritic materials, and are not noticeable unless the light falls on the surface at an angle.

Certain of the varieties of marble obtained here are white with golden-yellow veining, grays of various shades, gray veined and mottled with white, pink, and yellow; pale green, grass-green, green with black and white, green with pink and white, black and white, plain black, and of other color combinations. (See Pls. XX to XXII.) In thin sections the green color appears to be due to chloritic material and possibly to some epidote. Among the trade names adopted by the company to designate some of the more striking varieties of the marble are "white and gold," "Confederate gray," "moss-agate green," "raven-black," and "jewel marble." The last is a veined or mottled stone generally showing strong contrasts between dark green, white, and pink and having a few pink calcite crystals either isolated or in bunches. The color of these calcite crystals, which suggests that of garnet, is due to the presence of disseminated fine grains of hematite.

Thin sections of five samples of marble from the Alaska-Shamrock claims were examined microscopically by T. N. Dale and G. F. Loughlin.

A section of the grayish-white marble showed an uneven texture with streaks still firmer than the very fine grained groundmass. These streaks contained also sparse quartz and muscovite. Micrometer measurements of the general groundmass gave a grain diameter ranging from 0.025 to 0.5 millimeter, mostly between 0.05 and 0.25 millimeter, with an estimated average of 0.1 millimeter.

A section of the banded white and blue marble is composed of light bands of regular texture alternating with bands of finer grains with much graphite, a few large calcite grains, and a little muscovite. The grain diameter of the white bands ranges between 0.05 and 0.5 millimeter, mostly 0.125 to 0.25 millimeter, with an estimated average of 0.125 millimeter.

A section of the banded green and white marble showed a groundmass of white bands containing many grains of plagioclase (?) and some of quartz measuring as much as 0.25 millimeter, with irregular bands of fine-grained epidote, chloritic material, calcite, and a little quartz. The groundmass has grain diameters of 0.025 to 0.32 millimeter, mostly 0.075 to 0.2 millimeter, with an estimated average of



0.075 millimeter. The calcite grains in the green bands have a grain diameter of about 0.06.

A section of grass-green marble consists of calcite plates, mostly untwinned, quartz grains, with rarely one of plagioclase, finely disseminated minute scales of chlorite, a few of biotite, and plates and quartz grains and some pyrite. The calcite plates measured by micrometer range between 0.02 and 0.094 millimeter, but mostly between 0.03 and 0.056 millimeter.

The section of the "jewel" marble was not measured for grain diameter. The groundmass is mainly calcite, but chloritic material and quartz occur, especially in the green areas. The red or "jewel" areas consist of calcite colored by hematite grains. These red areas are crossed by colorless veinlike streaks which may be aragonite or possibly strained calcite.

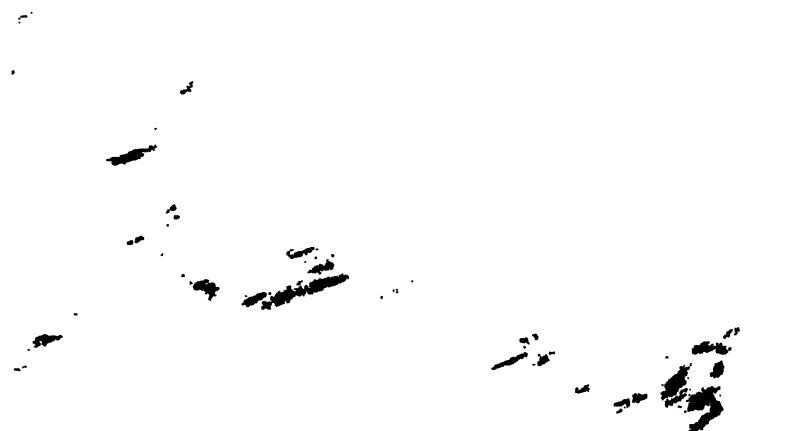
Two samples analyzed by R. K. Bailey show high percentages of insoluble material and a moderate percentage of magnesia.

Analyses of marble from Dickman Bay.

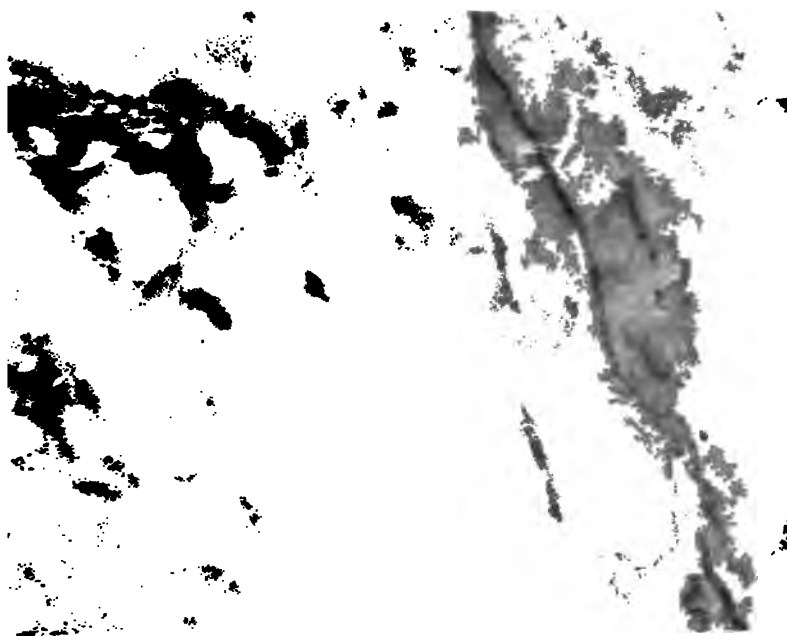
	"Jewel" marble.	Dark- green marble.
Insoluble matter.....	22.84	37.32
Calcium carbonate (CaCO_3).....	74.61	58.40
Magnesium carbonate (MgCO_3).....	3.25	6.61

Prospects.—Three or four openings have been made on marble beds that crop out on the shore of Shamrock Inlet. At the prospect nearest the southeast point of the peninsula work was in progress in October, 1912. A small clearing had been made, several houses and a machine shop had been built, and blocks were being detached from a ledge of marble banded with dark-gray and white veins. The marble is brittle and somewhat schistose and splits readily along the laminations. On weathered surfaces the harder portions of the rock stand in relief above the more calcareous portions. A hand derrick was used here in clearing away stumps and raising blocks of marble.

Northeastward along the shore of the inlet other openings disclose alternations of light-colored and blue marble. One opening is in beds of very fine grained cream-colored marble slightly veined with yellow. At this place the beds are exposed for about 100 feet horizontally and 30 to 40 feet vertically. The strike is N. 75° W., and the beds stand nearly vertical. The surface of the beds is rough and fractured, with deep crevices produced by solution, and the mass is cut by a basaltic dike that has been faulted and twisted since its intrusion into the marble. Where badly fractured the beds will have to be quarried deeply in order to ascertain the possibility of obtaining blocks of adequate size.



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4D WHITE MARBLE WITH FAINT GRAYISH-GREEN VEINS, FROM ALASKA SHAMROCK MARBLE CO.'S PROPERTY, DICKMAN BAY.

5D GRAY MARBLE WITH YELLOWISH STREAKS AND WHITE CLOUDED AREAS, FROM ALASKA SHAMROCK MARBLE CO.'S PROPERTY, DICKMAN BAY.

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Two of the most interesting prospects are on a ridge extending northwest from the camp, in the direction of the strike of the rocks. The marble ledge that has been opened is 70 to 75 feet wide between two dikes that have weathered more slowly than the calcareous mass and that form walls on either side of it. At the upper opening, about 800 feet from the shore and 350 to 400 feet above tidewater, the marble is principally green. The beds are exposed for about 150 feet along the strike. The green color appears to become paler toward the northwest, although small patches of stone among the paler areas are of fully as deep a green color as any others in the deposit. The deeper shades of green seem also to occur nearest the top or surface edges of the beds. Prospecting with a core drill is recommended if more definite knowledge is desired regarding the continuation of green shades in depth. The rock here is not so badly fractured at the surface as along the shore, and it is possible to get out some very good sized blocks without quarrying deeply. A 1-ton block, which was moved on skids down the trail to the beach, has already been shipped to Portland, Oreg. Another opening on this same ledge was noted about 600 feet from the beach and about 200 feet above water. The beds here are banded with dark blue or gray and white near the southwest wall, but the blue bands change to dark green near the middle of the ledge. A small mass of garnet-colored calcite was noted in the rock at this place.

At these prospects it has been necessary to clear away a vigorous growth of timber and to strip off a cover ranging from a few inches of moss on the exposed places to soil 6 or 7 feet thick in the crevices and hollows in the rock.

Other prospects of the Alaska-Shamrock Marble Co. are situated on this peninsula on the north shore of Dickman Bay and extend up a small bight about three-quarters of a mile from the extremity of the peninsula. The dip and strike and the position of the beds exposed here indicate that they are probably continuations of the ledges near Shamrock Inlet. Diabase dikes have intruded the beds in this locality, and the surface exposures of the stone show much jointing and fracturing. The marble occurs in various shades of white, bluish gray, and green. In polished samples some of the green marble compares favorably with the "verde antique" types produced in the United States. The beds crop out in bold cliffs on both sides of the small cove, and they also form its floor and extend inland beyond the head of the cove. This area was the first one to be prospected by the Alaska-Shamrock Marble Co. The prospecting has been done mainly by hand drilling and loosening blocks with black powder. Considerable material has been shipped to Portland for exhibition. Another possible resource of this company is the gray granite that

crops out on the shore of Dickman Bay between the two marble localities.

A letter from the company dated September 9, 1914, indicates that prospecting had been continued with encouraging results consisting of additional discoveries of large quantities of attractive marble, including the "jewel" stone, pink and gray, "Irish green," white and gold, verde antique, dark stone with a grain resembling that of fir when cut in the direction of the grain, and stone having intermingled green, black, gray, white, and pink colors. Eight blocks having an average weight of 7 tons each and two blocks of 12 tons each are reported to have been shipped from this locality to Portland, Oreg.

Some decorative work in Portland is reported to have been done with this marble, such as the entrance to the Charlotta Court at Seventeenth and Everett streets, in which was used a reddish-brown and white-banded combination with a background of Colorado Yule marble, and the entrance to the Majestic Theater at Park and Washington streets (see Pl. XXVI), which was paneled with black and white brecciated marble having a garnet-colored stain in some of the black areas.

The reported discovery of a large quantity of verde antique marble seems to be especially important, as there is a considerable demand for marble of this type for trimmings in interior decorative work, and it is beginning to be used for exterior work, such as borders for doorways or show windows.

Much of the marble available in this locality is of great beauty when finished, but the geologic structure of the beds suggests that there will probably be considerable waste in quarrying and in finishing. Much more prospecting and development work must be done in order to ascertain whether or not the properties can be exploited on a commercial basis. All the properties are situated most favorably for shipping quarry products. Deep water extends practically to the shore line, except in the small cove, and both Dickman Bay and Shamrock Inlet afford roomy and sheltered harbors.

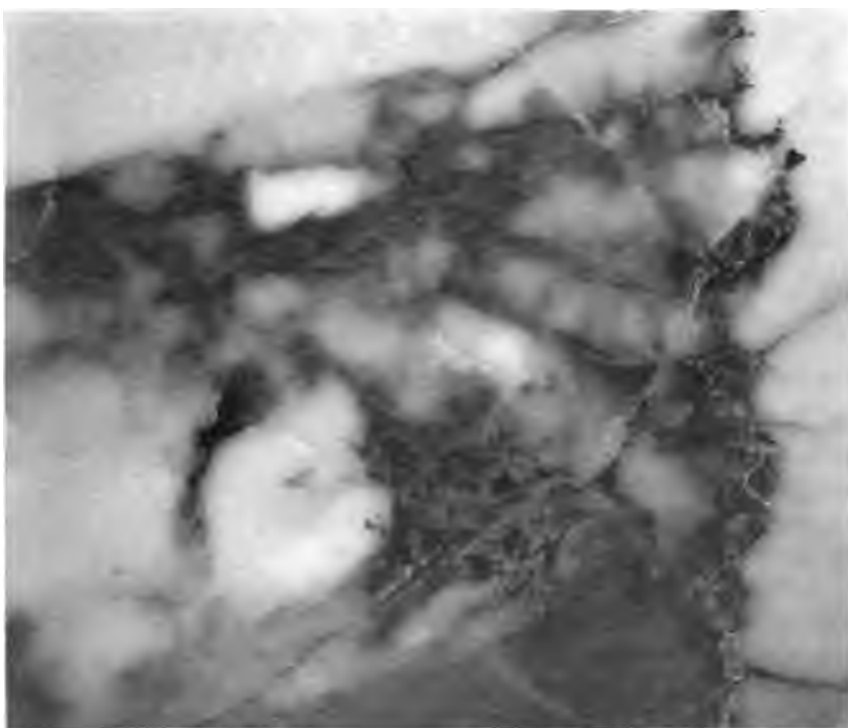
MAINLAND EAST OF WRANGELL ISLAND.

A long, narrow belt of crystalline limestone, containing true marble in many places, extends in a northwesterly direction on the mainland for a distance of about 17 miles, beginning at Blake Channel and lying nearly parallel to Eastern Passage.¹ Blake Channel itself follows the strike of this belt and may represent a drowned valley developed along these comparatively soluble rocks. At the south

¹ U. S. Geol. Survey Bull. 847, pl. 3, 1908.



A



B

B FINE-GRAINED GREEN AND WHITE BRECCIATED MARBLE FROM ALASKA-SHAMROCK MARBLE CO.'S PROPERTY, DICKMAN BAY.

A FINE-GRAINED DARK GRAYISH-GREEN AND WHITE BRECCIATED MARBLE ("BLACK A" FROM ALASKA-SHAMROCK MARBLE CO.'S PROPERTY, DICKMAN BAY.

end of Blake Channel certain small areas of marble, including Ham Island and areas on the north and south sides of Bradfield Canal, are also practically in strike with this belt. The metamorphism of this limestone to marble has probably been caused by the intrusion of wider belts of granite to the east on the mainland and to the west on Wrangell Island. Metamorphic minerals such as talc are present in the marble deposit near the east end of Lake Virginia, described below.

Lake Virginia.—The upper end of Lake Virginia (formerly known as Mill Lake), distant about 4 miles from Eastern Passage and about 12 miles from Wrangell, cuts through this belt of marble (No. 50). The rock ranges from grayish-white and coarse-grained marble at the east side of the exposure to fine-grained bluish-gray and veined marble at the west. The fine-grained grayish and banded material predominates. Near the east side, near the contact with granitic intrusive rock, contact minerals of fibrous radial character are developed in the coarse-grained marble.

Three thin sections of marble from this locality were examined by T. N. Dale and G. F. Loughlin.

A section of the grayish-white marble showed a very uneven texture, being composed mainly of portions having two grades of fineness. Micrometer measurements of the grain diameter of the finer part showed a range from 0.074 to 0.555 millimeter, with an estimated average of 0.154 millimeter. The coarser part showed a grain diameter from 0.185 to 2 millimeters, mostly 0.37 to 1.1 millimeters, with an estimated average of 0.434 millimeter. A few grains of quartz are present.

A section of the gray marble showed an even texture and a grain diameter ranging from 0.05 to 0.62 millimeter, mostly between 0.125 and 0.375 millimeter, with an estimated average of 0.145 millimeter. According to the Rosiwal measurement the average grain diameter is 0.0054 inch, or 0.137 millimeter.

A section of the coarse-grained, nearly white marble containing a fibrous mineral in large radial aggregates consists largely of talc bands or fibers in extremely thin parallel and divergent aggregates 0.01 to 0.1 millimeter thick, between broader bands of calcite. Considerable carbonate is interleaved with the talc fibers. Here and there large plates of dolomite cross the foliation. Many minute crystals of pyrite rusting to limonite are present. It is suggested by Mr. Loughlin that the talc may have been derived through the complete replacement of tremolite or diopside, or that it may be a primary metamorphic mineral formed under less heat and pressure than required to form tremolite and diopside. Local conditions favor the possibility that the talc is a primary metamorphic mineral.

The chief constituents of this rock as determined by R. K. Bailey are as follows:

Analysis of talcose marble from deposit near Lake Virginia.

Insoluble matter	19.06
Calcium carbonate (CaCO_3)	53.69
Magnesium carbonate (MgCO_3)	26.10

This marble belt is exposed at short intervals along the south shore of Lake Virginia for a distance of about 1,000 feet and was traced toward the southeast for more than half a mile. The beds range from thin and schistose to massive. They dip steeply toward the northeast and strike N. 15° – 25° W. On the southwest the belt is bordered by schist; on the northeast, although no direct contact is visible, boulders of granite indicate the character of the adjacent rock.

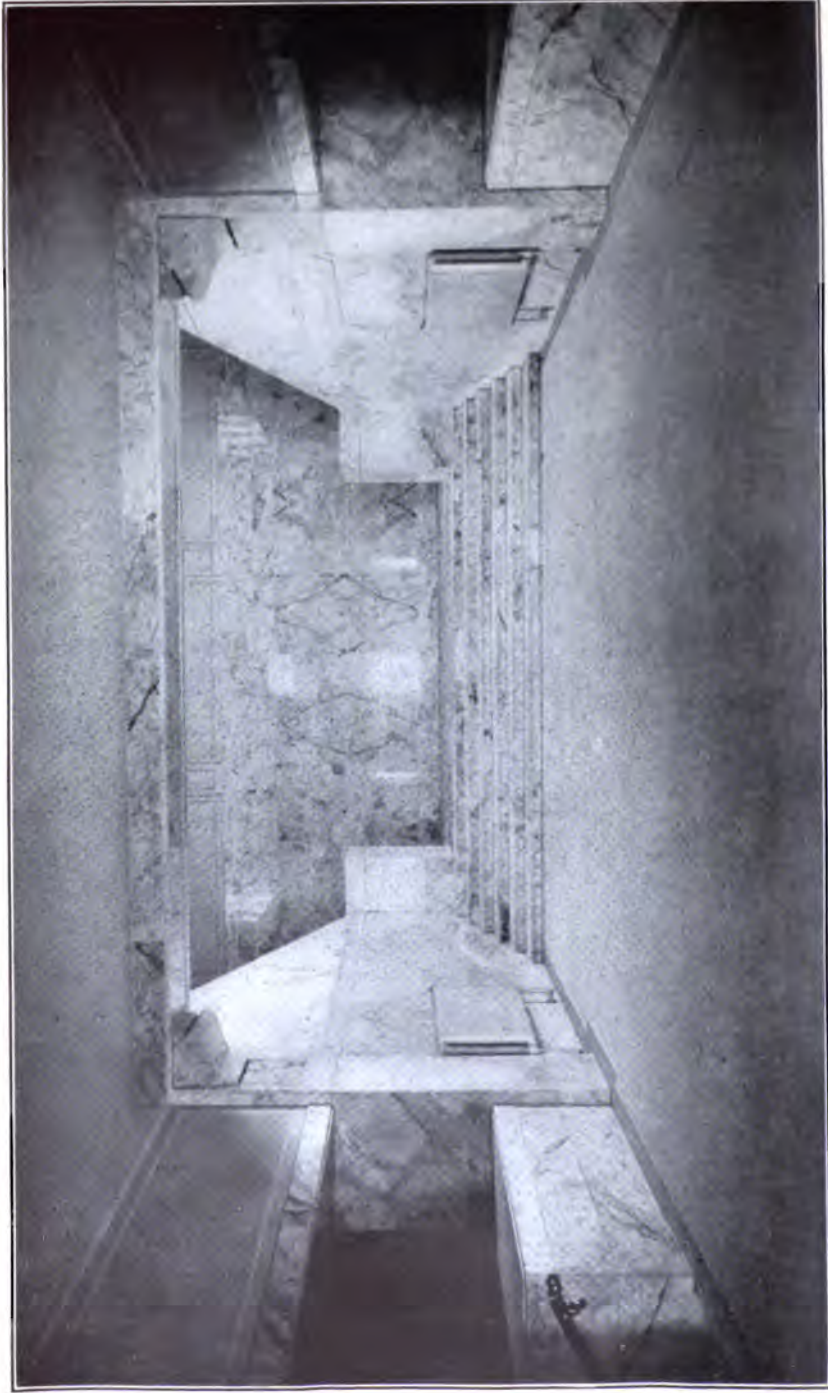
Several marble claims have been staked on the outcrops along the shore of Lake Virginia, though there was but little evidence of assessment work or prospecting when the locality was visited by the Survey party in September, 1913. At one point a short tunnel had been driven in pyritiferous schistose beds in search of metalliferous ore. Until considerable prospecting with a core drill is done, nothing definite can be known as to the probable value of this marble deposit. Back from the lake shore the surface is rough and covered generally with a heavy growth of timber and moss, with the usual soil, muck, and underbrush in the low places. If marble of value should be found, quarries could be opened near the lake shore, and blocks could be transported on tram cars carried on a barge to the foot of Lake Virginia, a distance of about 2 miles, beyond which a tramway $1\frac{1}{2}$ miles long would have to be built down Mill Creek to deep water in Eastern Passage. The level of the lake is probably about 200 feet above the sea, and as there is a large overflow from the lake, considerable water power might be developed here. In fact, it is said that a small fall near the shore of Eastern Passage was once so utilized.

Blake Channel.—On Blake Channel 8 or 9 miles southeast of Lake Virginia this belt of marble crops out on tidewater (No. 51). Here the marble is medium grained to coarse grained, mostly bluish in color, and generally banded with gray. In places the color is light blue to white. A thin section of the gray and blue banded material examined by T. N. Dale showed an even texture, crossed by parallel graphitic (?) streaks with some pyrite. The calcite shows much close twinning. The grain diameter ranges from 0.11 to 1.1 millimeters, mostly between 0.185 and 0.74 millimeter, with an estimated average of 0.275 millimeter. The beds stand nearly vertical and strike about N. 10° W. The marble is exposed for 200 or 300 yards along the shore, rises steeply, and extends an undetermined dis-



ENTRANCE TO YEON BUILDING, PORTLAND, OREG., DECORATED WITH TOKEN MARBLE.

Note the matched panels produced by sawing slabs of clouded marble.



CORRIDOR, UNIVERSITY OF UTAH, SALT LAKE CITY, UTAH, DECORATED WITH TOKEN MARBLE.

tance into the mountains toward the north-northwest. On the west the bordering rock is schist, and on the east the marble is in contact with an intrusive mass of quartz-bearing basalt. A mass of fine-grained gray granite forms a cliff on Blake Channel about 3 miles west-northwest of this locality. Five claims of 20 acres each

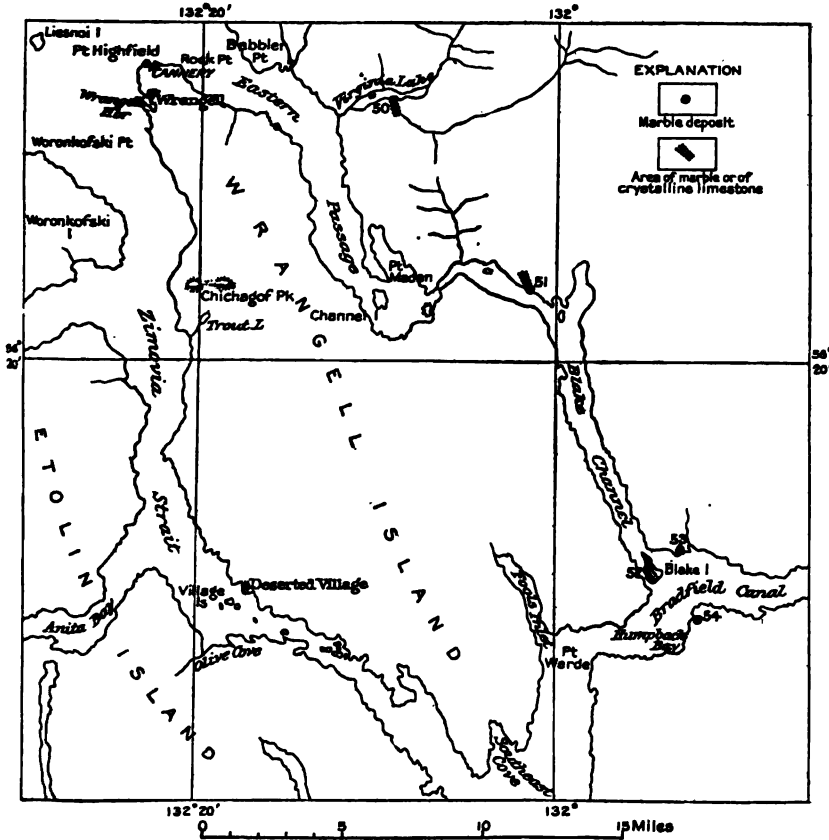


FIGURE 4.—Map showing marble deposits examined on mainland east of Wrangell Island and on Ham Island. From Coast and Geodetic Survey chart 8200.

have been staked on this marble by Frank Spalding, of Wrangell, who has opened several prospects.

BLAKE OR HAM ISLAND.¹

Ham Island (see fig. 4) lies in Blake Channel at its junction with Bradfield Canal about 25 miles southeast of Wrangell (No. 52). It is about $1\frac{1}{4}$ miles long and is composed largely of crystalline limestone interstratified with beds of calcareous schist. These beds dip steeply northeast and strike about N. 35° W., falling in line with the

¹ Blake Island by decision of the United States Geographic Board; Ham Island on the Coast Survey chart and in local usage.

long lens or belt of crystalline limestone that crops out on the mainland about 10 miles northwest of Ham Island.

The marble beds have been extensively tested on Ham Island, and deposits have been prospected also on the adjacent mainland east

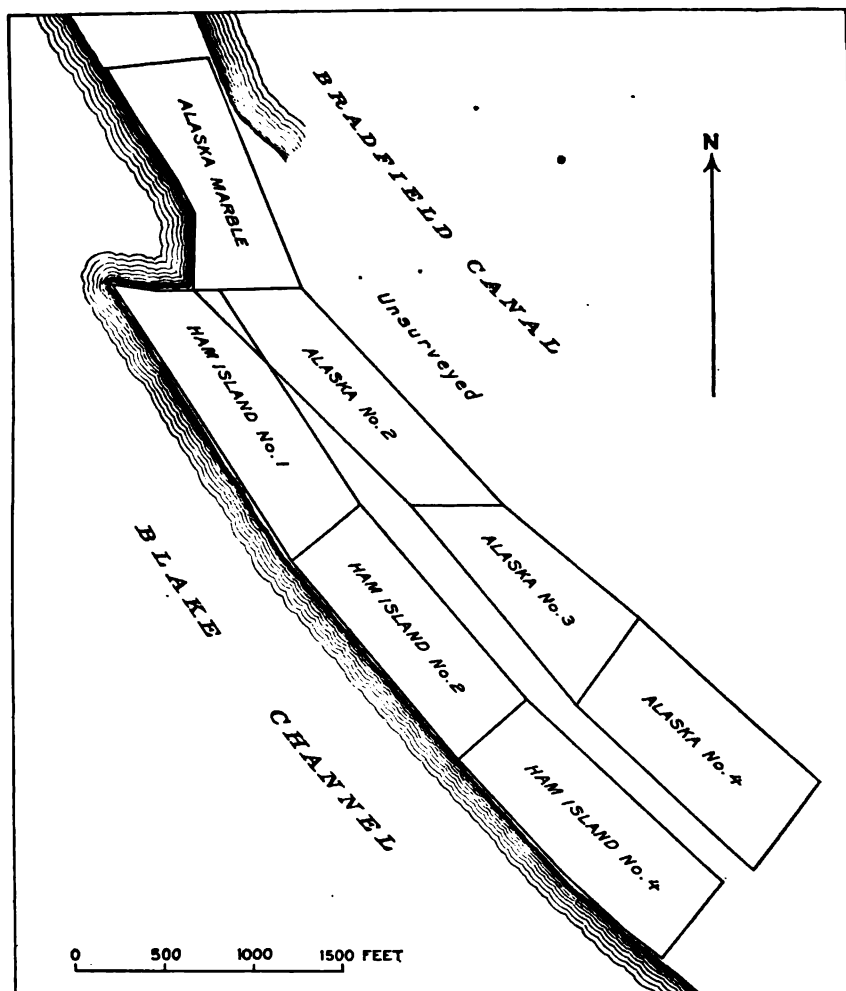


FIGURE 5.—Sketch map showing claims of Vermont Marble Co. on Ham Island.

and southeast of the island, with the result that claims have been located in all these places. In the northern part of Ham Island the greater part of the marble available is coarse grained, and ranges in color from light grayish blue to dark gray; but some of it is nearly white. A little fine-grained marble, mostly white, occurs in the southeastern part of the island. The strata have been crumpled and folded and are slightly schistose in places, but the stone gen-



**LOBBY OF ISAACS BUILDING, LOS ANGELES, CALIF.; FLOORS, STAIRS, AND WALLS
OF TOKEEN MARBLE.**



ENTRANCE TO MAJESTIC THEATER, PORTLAND, OREG., DECORATED WITH COLORED MARBLE FROM

ally seems sound, and the rock is not so badly checked and fractured as in certain other marble areas in southeastern Alaska. Several systems of joint planes intersect the beds, but the joints are spaced widely enough not to interfere greatly with quarrying. The marble occurs in beds of varying thickness, generally 2 to 4 feet or more, that strike northward and dip at an angle of 50° or more toward the east. In the eastern part of the island, south of the middle, some beds of fine-grained white marble, 20 feet thick, alternating with coarser crystalline marble, have been revealed by the core drill. In some places the presence of many veins and nodules of quartz and chert in the white marble has been shown by drilling perpendicular to the bedding, and it is feared that they may present a serious obstacle to the utilization of these beds. The quartz veins are generally from a fraction of an inch to a few inches in thickness, though at least one vein a foot thick has been noted.

Two groups of claims on Ham Island, owned originally by Woodbridge & Lowery and by Mr. Miller, have been purchased by the Vermont Marble Co. (see fig. 5) and are being thoroughly prospected by that company, but up to 1914 the results had not warranted opening a commercial quarry. Many large blocks of marble were quarried by the former owners, and from these blocks tombstones and small blocks have been cut and polished by hand for local use.

Thin sections of two samples of marble from Ham Island were examined by T. N. Dale. One section of medium-grained grayish-blue marble showed an irregular texture, with grains mostly elongate and much twinned. Graphite is present. Measurements by the micrometer showed a grain diameter ranging from 0.28 to 2.52 millimeters, mostly between 0.84 and 1.68 millimeters. The Rosiwal measurement showed an average diameter of 0.0127 inch, or 0.3235 millimeter. The other section was taken from very coarsely crystalline grayish-white stone and showed a grain diameter ranging from 1.39 to 3.64 millimeters. The other coarse varieties fall between these two grades.

MAINLAND NEAR HAM ISLAND.

On the mainland in the vicinity of Ham Island the Vermont Marble Co. holds two claims of 160 acres each about 1 mile east of Ham Island on the north side of Bradfield Canal (No. 53), and two claims 1½ miles southeast of Ham Island on the south side of Bradfield Canal (No. 54). Neither of these properties had been developed at the time the writer was at Ham Island.

REVILLAGIGEDO ISLAND.

Prospecting for marble on Revillagigedo Island has been carried on at intervals for about 15 years. Little of importance has been done, however, since the survey of the Ketchikan district by the

Wrights,¹ who noted the important features of the marble deposits on this island as follows:

A well-defined limestone belt traverses the eastern portion of Revillagigedo Island in a northwesterly direction and is exposed in Thorne Arm, Carroll Inlet, and George Inlet. Its widest development is on the north side of George Inlet, near the head [No. 55], where marble claims known as the Bawden group were located in 1904. The deposit is included in the crystalline schist near the contact with the less-altered slates to the southwest. The marble beds range from 10 to 20 feet in width and are separated by strata of calcareous schist. Their strike is northwest and their dip northeast. The marble is exposed in

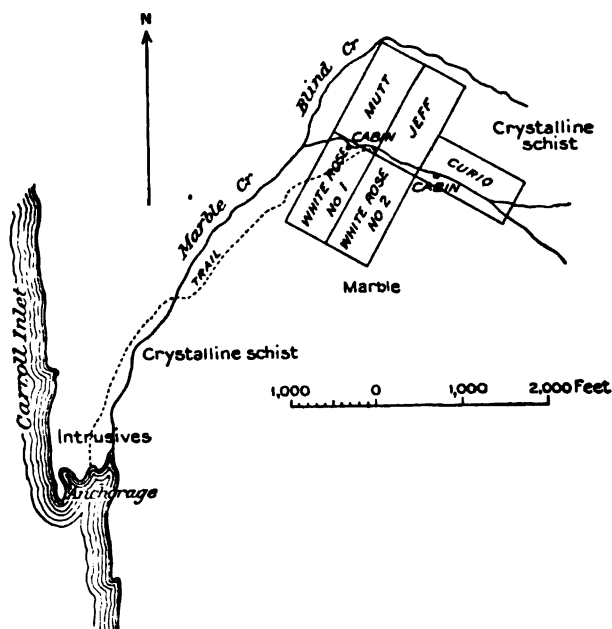


FIGURE 6.—Sketch map of Dickinson & Bell marble claims on Revillagigedo Island near Carroll Inlet.

cliffs near tidewater and is of good quality, being relatively free from fracture and joint cracks, finely crystalline, and from white to gray in color. No large developments have been started on this property.

In Carroll Inlet, to the southeast, claims have also been located on the same belt, but at this locality the deposit is not so extensive as in George Inlet.

In addition to these claims two groups were noted by the writer in October, 1912, on the east side of George Inlet. One (No. 56) lies 7 miles north of the point where George Inlet and Carroll Inlet coalesce, and the other (No. 57) about $6\frac{1}{2}$ miles north of that point. Only the shore exposures were visible at these places, and no prospects could be found. The rock exposed consists of grayish-white to gray fine to medium grained schistose marble, interstratified with and intersected by dikes of mica dacite. Nearly as much dike rock as

¹ Wright, F. E. and C. W., op. cit., pp. 197-198, pl. 2.

marble is exposed on the beach at the southern locality. All the beach exposures of marble are very soft and saccharoidal, almost too soft to yield a hand specimen. The beds dip about 30° a little north of west. So far as these exposures indicate, little if any commercially valuable marble is present at either place.

In the summer of 1915 Theodore Chapin examined certain marble deposits along Carroll Inlet, and his notes given below are descriptive of the most valuable deposit:

A deposit of white marble is being developed near Carroll Inlet by G. E. Dickinson and B. Bell. The claims are on Marble Creek, a stream entering a cove on Carroll Inlet from the east about 10 miles from its head (No. 58). (See fig. 6.) From this cove a trail leads to the claims, a distance of about a mile and a half. The rock is exposed by surface cuts at several places and along Marble Creek for half a mile, the width covered by the claim locations. In this distance the rock shows little variation. It consists of white crystalline marble of even texture and of very fine grain. No analysis was made of the rock, but to judge from its slight effervescence with acid it is probably dolomite.

Timber suitable for cabins and other construction grows on the claims, and water power sufficient for quarrying could be obtained from Marble Creek. The fall of 300 feet between the claims and the beach in a distance of a mile and a half offers no serious difficulty in tram construction.

COMMERCIAL CONSIDERATIONS.

By E. F. BURCHARD.

FACTORS CONTROLLING VALUE.

The value of a marble deposit in southeastern Alaska can not be judged by small surface samples alone, although tests of such samples may be of considerable significance. The character of the deposit as a whole must be considered, or at least of so much of it as will be required for a quarry, as well as extent, color, lack of objectionable impurities such as silica, pyrite, argillaceous and organic matter, soundness, absence of fractures or joint planes and of intersecting dikes, facility of quarrying and loading on vessels, distance and freight rates to markets, and competition.

The feature that probably will cause the most serious hindrance to profitable quarrying in southeastern Alaska is the fracturing and jointing of the beds. Observations have shown that this condition is very prevalent at the surface in this region, and such quarrying and drilling as has been done has shown that fractures, or "shakes," as they are called locally, extend in places to a depth of at least 100 feet. It is of course possible that at greater depths sounder stone will be found, but it is not profitable to be obliged to reject a large percentage of waste simply because the quantity of available blocks of the requisite size is limited by the structure of the deposit. The

heavy rainfall and the influence of the dense vegetation in this region have softened the surface marble, in places, to surprising depths compared with those noted in well-known marble regions in the United States.

The practical judgment of a competent marble quarryman is necessary to decide many of the questions relating to the availability of the stone. Cross trenching, a common form of prospecting to determine the surface extent of a marble deposit, must be supplemented in southeastern Alaska by the core drill. A careful study should be made at the surface of the directions or strikes of the several systems of joints, their minimum, maximum, and average spacing, the direction and angle of their dip, and the nature of the fracturing that is not related to the systematic jointing. A sufficient number of holes should then be drilled to such depth and in such direction that a definite idea may be obtained as to the character of the beds below the surface, especially in relation to fracturing and jointing and the hardness of the marble.

Tests of the cores, including chemical analyses, measurement of size of grain, absorption, porosity, compressive strength, and polish, are all of great value, but satisfactory tests for strength and polish may not be practicable unless the core is 2 inches or more in diameter.

PROSPECTING.

Important technical details of modern prospecting of marble deposits have been recently published in a paper by Bowles,¹ in which the following suggestions are given in much greater detail.

Value of geologic maps.—Some marble beds crop out in long, narrow bands, which may extend for many miles. These bands represent truncated edges of folded strata and they may be curved or straight, their form depending on the topography and on the nature of the folds. Other marble beds have irregular outlines owing to faulting or to incomplete metamorphism of the original limestone mass. Much of the rock surface may be covered with gravel, sand, or clay to a considerable depth. The geologist may, by a careful study of outcrops exposed here and there, obtain a knowledge of the chief structural features and may thus determine the position, attitude, and thickness of the marble beds with a fair degree of accuracy, even if they are almost entirely hidden by surface débris. If geologic maps of marble areas are carefully made they are of inestimable value to the marble prospector. By accurately locating himself in the field and carefully studying a geologic map the prospector may determine the position of the marble beds beneath the surface and

¹ Bowles, Oliver, The technology of marble quarrying: Bur. Mines Bull. 106, pp. 39-46, 1916.

know something of their extent and attitude, although the beds are unseen. It is important, therefore, that all available geologic maps of the region be consulted freely.

Detailed prospecting.—Knowledge of the suitability of any particular site can be gained only by detailed prospecting, including determinations of the depth of overburden and of surface decay of the rock and of the extent, quality, impurities, and soundness of the deposit. It is unwise to proceed with development work without reasonable assurance that an available mass of sound and attractive marble is sufficiently uniform in quality and abundant in quantity for profitable exploitation.

Determination of overburden.—The depth of stripping necessary may be determined at small cost by putting down drill holes. Such preliminary tests may save much wasteful expenditure, for in places stripping has been attempted without any previous investigation of the depth of soil to be removed, and great loss has resulted from thus working blindly.

In estimating the necessary cost of stripping for a new quarry the attitude of the marble beds must be taken into account. If the beds are flat a greater area of rock must be uncovered than if they are steeply inclined or vertical.

Conditions relating to disposal of strippings are of great importance. In certain places it is a matter of some difficulty to find a suitable place in which to deposit the soil that must be removed; in other places the soil may be carried to neighboring valleys or low-lying areas and usefully employed.

Surface study.—Surface observations of the marble beds are of great value, especially as regards jointing. The process of weathering tends to emphasize all unsoundness and thus facilitates the study of joint systems. Exposed surfaces may also permit a determination of dip and strike and the thickness of the beds. In determining the quality of a marble deposit a study of uncovered knobs or ledges should not, however, be deemed sufficient. On account of surface weathering the top rock may differ materially from the deeper parts of the deposit. Moreover, the number and spacing of joints at the surface may be no indication of the prevailing conditions at depth. In order to obtain a fair idea of the quality and soundness of the marble and the supply available, drill cores should be taken at several points.

Diamond-drill prospecting.—The ordinary diamond drill will give the necessary information regarding color, uniformity, and general appearance of the stone, and also the extent of the formation. It will not, however, give definite information concerning the dip and the strike or the unsoundness of the marble. If drill cores come out in long, unbroken sections that show no indication of cracks, it may

be assumed that the rock is fairly sound. If, on the other hand, the core is in short sections, the rotation of the drill will as a rule have so worn and rounded the broken ends that it will be impossible to determine whether the breaks are due to natural planes of weakness in the rocks or to the process of drilling itself.

A method of prospect drilling that has been employed involves the use of the double-core barrel drill, consisting of an outer and an inner tube, which was designed primarily for drilling bituminous coal and operates in such a manner as to bring out a core from delicate material with a minimum of breaking or other damage.

The use of such a drill enables the prospector to judge the unsoundness of the marble at points beneath the surface, for by examination of the ends of the sections of drill core he can generally interpret the breaks and state whether they are due to natural joint planes in the rock or to the process of drilling. If the cores are properly oriented, the proximity and direction of all natural cracks in the rock and in the immediate vicinity of the drill holes may thus be ascertained. If the marble deposit is well exposed, the dip and the strike may be determined from examination of the outcrops. If, however, it is completely buried, these features may be determined from the drill cores if they are carefully oriented.

Information should be obtained with a minimum number of drill holes. In this respect prospecting for marble differs materially from prospecting for metalliferous ores, as the soundness of the ore is not important, whereas with the marble every crack or cavity increases the proportion of waste in the quarried product. A drill hole in a quarry may be nearly as objectionable as a crack. If the deposit lies flat or nearly so, a single well-placed core driven entirely through the deposit will give information as to the character of the marble and show whether it is one homogeneous mass or is divided by streaks of color or open beds into different layers and whether the layers differ in character. If, however, the deposit dips at a moderate angle and is comparatively thick, the best way to determine its thickness and the character of its beds is to lay out a line of drill holes at right angles to the strike. The first drill hole that penetrates the upper beds should begin in the hanging wall, the bed immediately overlying the marble bed. The holes should be of such depth and spacing that the bottom of a hole in the upper beds will penetrate the same layer as the top of the neighboring hole on the side toward the footwall. The core nearest the footwall should reach and penetrate this wall. By this method a series of core holes of moderate depth will supply samples from all the beds, and the relatively high cost of drilling deep holes penetrating the entire deposit will be avoided.

A marble deposit in which the color, texture, or other qualities are highly satisfactory may nevertheless not warrant commercial development because of joints and cracks. Most joints occur in two systems, the openings in each system being approximately parallel with one another and the two systems being more or less nearly at right angles. In Alaskan deposits generally more than two systems are present. The spacing of the cracks varies widely in different deposits and even in different parts of the same deposit. In many places cracks persist to almost any depth to which quarrying operations have been carried. It is important to determine, if possible, which of the cracks that appear at the surface are likely to persist, and also their nature and spacing in the deeper parts of the deposit. Where the cracks are nearly vertical a vertical core taken out of marble that is unsound may reveal the presence of only a few of the cracks. There, under such conditions, a vertical hole is not reliable as a means of estimating the unsoundness to be encountered.

It is practically impossible to take out good cores that are representative of the deposit from horizontal drill holes. The core from a horizontal hole invariably breaks into short pieces, which grind on each other, in spite of the use of the double-core barrel. Therefore, if the marble beds lie flat, or nearly so, unsoundness must be prospected for by inclined core holes; otherwise the cores will not yield the information desired. If the marble deposit stands at a high angle, one set of core holes driven in an inclined direction and penetrating from the hanging wall to the footwall, or the reverse, can be laid out so as to give the information required as to the quality of the stone and also the unsoundness. It is important to take cores near the top, near the middle, and near the bottom of the deposit, because the unsoundness may vary in different beds, as well as in different parts of the same bed.

In order to get the fullest information from an inclined core hole the core parts should be matched up from one end to the other and placed as fast as obtained on an inclined rack that will hold the core in a position parallel with the hole from which it was taken. While the core is in this position the compass bearing of the cracks and also the angle that they make with the core can easily be determined. From this information a plan may be made from which the probable percentage of marble unaffected by unsoundness may be computed with reasonable accuracy.

As a rule, drill cores are not preserved with sufficient care by quarrymen. They are often carelessly stored, lost, or given away as samples. It is important that every part of every drill core be carefully marked and stored for future reference. It must not be assumed that the value of drill cores disappears after their first investigation. They are invaluable records, which should be available at all times.

All drill cores should be polished on one side, in order to facilitate determination of color, uniformity, and degree of polish that may be obtained. It is well to supplement the evidence of the cores by stripping the marble along each line of holes, and also to dig a trench or two at right angles to each line of core holes, so as to expose the marble to some extent along the strike.

THE PROBLEM OF WASTE.

As the problem of waste is one of the most important to be considered in connection with the marble industry in southeastern Alaska, it seems fitting to refer here to certain principles discussed in the recent publication by Bowles,¹ who has made a study of marble quarrying with special reference to safety, efficiency of operation, and prevention of waste.

The problem of waste is twofold. In the first place it has to do with improved equipment and modern methods of excavation which tend to keep the proportion of waste at a minimum; and in the second place it deals with the various uses to which waste material may be applied. In other words, it is a problem, first, of waste elimination and, second, of the utilization of whatever waste is unavoidable.

Waste elimination is much more desirable than waste utilization. Methods that result in excessive waste should not be countenanced merely because an outlet has been found for waste material in the form of by-products. As a rule the cash return from quarry by-products is only a fraction of the production cost of the waste material from which they are supplied. As an illustration, it may be assumed that a moderate cost of marble excavation (in 1915) is 25 cents a cubic foot, or \$3 a ton. A fair price for riprap is 50 cents a ton, one-sixth of the cost of excavation. The quarryman seeks a market for riprap, not because the production of riprap is profitable, but for the reason that he prefers to obtain one-sixth of the cost of his waste material rather than to receive nothing at all. By eliminating a ton of waste he saves \$3, whereas by marketing it he saves only 50 cents.

WASTE ELIMINATION.

The loss of a part of the good stone is unavoidable. Channeling, drilling, scabbing, sawing, and coping are all necessary operations which use up an appreciable share of the stone. In addition to losses due to the processes of manufacture, more or less stone must be thrown away on account of imperfections. It is, however, the throwing away of masses containing many cubic feet of good stone, or the handling

¹ Bowles, Oliver, op. cit., pp. 108-120.

of an excessive amount of inferior material, which constitutes the serious and, for the most part, avoidable losses.

The natural imperfections in marble that constitute the source of the greater losses are unsoundness, strain breaks, impurities, and lack of uniformity either in color or texture.

Systematic prospecting is a first step toward waste elimination. Before operations are started the outcrop or stripped surface should be mapped carefully to show the direction of strike and dip and the directions of the chief joint systems. Naturally the quarry walls should parallel those rock structures that are most pronounced. If the beds are tilted and if inferior beds alternate with those of good quality, it may seem advisable to make the quarry walls parallel the strike and dip. If the rock is of uniform quality but intersected by prominent joint systems, the quarry walls should be parallel and at right angles to the chief joints, or possibly the contiguous walls should parallel the two chief systems of joints if these should meet at oblique angles. Careful mathematical calculations may be necessary before it can be determined definitely which plan will give the minimum of waste. If a mistake has been made in the original plan of quarrying, it is possible to change the plan and quarry parallel with the chief rock structures. By such a change, however, corners are left and the original floor space greatly reduced.

The depth of inferior rock due to surface alteration is an important consideration. Although the actual value of the untouched material may be negligible, the cost of handling great quantities of waste material adds greatly to the expense of quarrying. The removal of such material may, under certain conditions, be avoided by driving tunnels.

If the tunnel is driven in good marble a large quantity of good material is thus destroyed. If practicable, the opening should be driven in an inferior bed. The blasting required in tunnel work demands care to avoid shattering the good marble.

A condition of strain within the marble mass has in certain places caused so great a proportion of waste that the workings have been abandoned. The rock is under a severe compressive stress usually in one direction only. Quarrying relieves the stress at certain points, and the consequent expansion may cause fracturing. Furthermore, the expansion of one mass that is still in rigid connection with the main mass still under compression may cause irregular or oblique fractures to form between the two masses. In order to avoid the waste due to this cause relief should be afforded by uniform expansion of as large a mass as possible at one time. To this end a line of closely spaced deep holes should be drilled along each side of the quarry parallel with the direction of compression, with a similar line of holes across the quarry at

right angles to the first line. The rock will expand and close the holes in the latter line, and the strain will thereby gain relief. For a complete discussion of the problem of strain breaks the reader is referred to pages 123-145 of Bureau of Mines Bulletin 106.

Unsoundness is the most prolific source of waste, and the one that is receiving least attention in the majority of American marble quarries. Too great emphasis, therefore, can not be placed on this phase of the waste problem. Channeling regardless of unsoundness probably accounts for the loss of a greater quantity of good marble than any other single cause. Waste results wherever joints pass through blocks, and the waste becomes excessive when they pass obliquely. A reduction to a minimum of this form of waste involves first a modification of channeling and drilling directions in order that they may conform with the directions of the chief joint systems, and second a variation in the spacing of cuts to make them coincide with joints and thus eliminate the joints from the blocks.

In addition to the sources of waste discussed above, Bowles takes up in turn waste due to lack of uniformity, to irregular blocks, to impurities, to bad color, and to strain breaks in quarrying, and makes practical suggestions for overcoming to a large extent the influence of these disadvantages. He points out, for instance, that in quarrying marble varying in color or texture an endeavor should be made so to quarry as to produce material that can be closely classified, by drilling, channeling, and cross breaking, as nearly as possible along boundaries between different grades of material. In treating of waste due to irregular blocks he has sketched the various forms of irregular blocks as quarried, outlined the circumstances under which they are produced, and showed the necessity for taking into consideration the prevailing rock structure in laying out the quarry and in cutting out the blocks of marble. If the marble is sound right-angled blocks are doubtless the most economical, but in quarrying unsound or nonuniform material conformity with structure may demand that the block be acute-angled, and obviously this is the most economical form to produce under such circumstances. Bowles also points out that the nature of the product has an important bearing on the matter of waste, and that if the blocks are entirely cut into thin stock there should be relatively little waste from inclined blocks. He has summarized certain rules governing the shape of blocks as follows:

1. Effort should be made to produce right-angled blocks, unless there is a valid reason for doing otherwise.
2. Quarrying on a level floor and splitting diagonally to form monoclinic blocks may be justified where much thin stock is produced. If much cubic stock is desired, the quarryman should consider carefully the advisability of channeling on an inclined floor in order to produce right-angled blocks.

3. A direction of channeling that results in inclined beds separated by open bedding seams pitching into the corner of a quarry should by all means be avoided. The same is true of inclined beds that are not separated by open seams but have a decided rift or color distribution parallel with the bedding.

4. As regards unsound or nonuniform material, although an effort should be made to avoid oblique angles, conformity of cuts with structure is, as a rule, more economical than right-angled cuts.

With regard to the avoidance of waste due to impurities, such as silica, dolomite, pyrite, and mica, the chief advice given by Bowles is to avoid so far as possible the quarrying of marble beds containing these minerals, especially if the material is to be used for exterior work.

WASTE UTILIZATION.

Although the proportion of waste may be kept at a minimum by the adoption of economical quarry methods and efficient machinery, there is always more or less unavoidable waste. The second phase of the problem of rock waste therefore is concerned with utilizing the waste material. Many manufacturers have found that the manufacture and sale of by-products from otherwise waste materials have placed their industries on a profitable basis. There are various difficulties in the way of developing waste utilization so far as most marble deposits in Alaska are concerned. The lack of a local market for rock products hinders activity. Freight rates to possible markets may be excessive.

Among the important uses that have been suggested for waste marble that might be applicable in Alaska and on the Pacific coast are in riprap, for shore protection; for road material; for burning into lime; for use in a pulverized form for improvement of soils; and for smelter flux.

LOCAL SAWING PLANTS.

Thus far the products of Alaska marble quarries have been confined practically to marble for interior finishing (see "Uses," p. 110), and the percentage of waste in quarrying is necessarily great, because it does not pay to ship blocks that can not be almost entirely sawed into large and perfect slabs for polishing. Much of the marble appears to be of suitable character for exterior construction and local sawing plants might produce much dimension marble from blocks of such stone that would otherwise be rejected. Small polishing plants might also utilize much of the waste marble by working it up into the smaller slabs required for base boards, tiles, plumbing fixtures, moldings, and the like. A small sawing plant was installed at one quarry in southeastern Alaska, but operations were soon discontinued and no figures are available as to the relative costs

of operation there and on Puget Sound; it is understood, however, that the high cost of coal in this part of Alaska makes manufacturing generally rather expensive. Moreover, the Puget Sound cities are supplied with relatively cheap electric power.

WATER POWER AND ELECTRICITY.

In southeastern Alaska, according to Canfield,¹ water power has been developed at 15 or more places, aggregating 35,100 horsepower. It is reported that abundant water power is available on Kosciusko Island, near Holbrook, less than 4 miles from the marble quarries on Marble Island. To deliver electric power to Marble and Orr islands a cable would have to be laid across a channel measuring, according to the Coast and Geodetic Survey charts, about 3,400 feet in width and 120 feet in depth; or else a line several miles longer would have to be built around the head of Tokeen Bay. In the southeastern part of Prince of Wales Island and on Revillagigedo Island the appearance of certain mountain streams and waterfalls suggests the possibility of power not yet utilized. It should be stated, however, that none of these streams have been studied by the writer with reference to their source of supply, and that unless fed from natural reservoirs such streams can not be relied on to furnish power throughout the year.

A systematic investigation was begun by the Geological Survey in cooperation with the Forest Service in the spring of 1915, to determine the location and the feasibility of water-power sites in southeastern Alaska, for it was realized that lack of definite information in regard to the quantity of water available and other physical factors that determine the feasibility of a power site has been one of the principal impediments to development. From the preliminary report² on these investigations the following data are quoted which appear to be of interest in connection with the possible development of marble deposits:

In the summer of 1914 Leonard Lundgren, central district engineer of the Forest Service, made a reconnaissance of water-power sites in southeastern Alaska to determine the possibility of establishing the pulp industry in the Tongass National Forest, which covers a large part of southeastern Alaska. In connection with this reconnaissance a census of water powers was taken (see following table), which has been revised by Mr. Lundgren to January 1, 1916, and is here published by courtesy of the Forester.

¹ Canfield, G. H., *Water-power investigations in southeastern Alaska*: U. S. Geol. Survey Bull. 642, p. 106, 1916.

² *Idem*, pp. 105-108.

Developed water powers in southeastern Alaska January 1, 1916, in horsepower.

[Prepared by Leonard Lundgren, district engineer, U. S. Forest Service.]

Ketchikan region :

Citizens Light, Power & Water Co.....	2,000
New England Fish Co.....	2,200
Miscellaneous plants.....	1,000
	<hr/> 5,200

Wrangell region..... 0

Sitka region :

Sitka Wharf & Power Co.....	350
Chichagof Mining Co.....	500
Miscellaneous plants.....	150
	<hr/> 1,000

Juneau region :**Alaska-Treadwell Mining Co. :**

Douglas Island plant.....	4,000
Sheep Creek plant.....	4,100
Nugget Creek plant.....	5,700
	<hr/> 13,800

Alaska-Gastineau Mining Co. :

Salmon Creek plant, No. 1.....	4,000
Salmon Creek plant, No. 2.....	4,000
Annex Creek plant.....	5,000
	<hr/> 13,000

Alaska Electric Light & Power Co..... 1,000

Miscellaneous plants..... 1,000

28,800

Skagway region..... 100

35,100

During the last few years some large water-power plants have been installed near Juneau to supply power for mining, and attention has been called to the feasibility of improving other power sites in that region and elsewhere in southeastern Alaska, to meet the increasing demand for power to be used in mining, lumbering, and fisheries, and the possible future demand for its use in the manufacture of wood pulp and electrochemical products. The streams on which it is possible to develop power and the bays or other water bodies into which these streams discharge are listed in the following table:

*Streams affording power sites in southeastern Alaska, with position or water bodies into which they flow.***Mainland.**

- Porcupine River, near Porcupine.¹
- Endicott River, west coast of Lynn Canal.
- Cowle and Davies creeks, Berners Bay.
- Lemon Creek, near Juneau.²
- Carlson Creek, Taku Inlet.³
- Turner Lake outlet, Taku Inlet.⁴

¹Gaging station maintained in 1909 by Porcupine Gold Mining Co.²Gaging station being maintained by mining company of Juneau.³Gaging station being maintained by Alaska-Gastineau Mining Co., of Juneau.⁴Gaging station maintained in 1908 and 1909 by Alaska-Treadwell Gold Mining Co.

Speel River, Speel River project, Port Snettisham.
Grindstone Creek, north shore of Stephens Passage.
Rhein Creek, north shore of Stephens Passage.
Long Lake outlet, Speel River project, Port Snettisham.¹
Crater Lake outlet, Speel River project, Port Snettisham.¹
Tease Lake outlet, Speel River project, Port Snettisham.
Sweetheart Falls Creek, south arm of Port Snettisham.¹
Port Houghton, Stephens Passage.
Farragut Bay, Frederick Sound.
Mill Creek, near Wrangell.²
Bradfield Canal, upper end of Cleveland Peninsula.
Smugglers Cove, southeast shore of Cleveland Peninsula.
Helm Bay, southeast shore of Cleveland Peninsula.
Shelockham Lake outlet, Bailey Bay.¹
Chickamin River, east shore of Behm Canal.
Rudyerd Bay, east shore of Behm Canal.

Baranof Island.

Port Conclusion, southeast coast.
Patterson Bay, east coast.
Red Bluff Bay, east coast.
Cascade Bay, east coast.
Baranof Lake outlet, Warm Spring Bay, east coast.²
Kasnyku Bay, east coast.
Green Lake outlet, Silver Bay, west coast.²
Necker Bay, west coast.
Deep or Redoubt Lake, west coast.

Chichagof Island.

Slocum Arm, west coast.
Sulola Bay, Peril Strait.
Khaz Bay, west coast.
Freshwater Bay, east coast.
Sitkoh Bay, southeast coast.
Basket Bay, southeast coast.

Admiralty Island.

Kootznahoo Inlet, west coast.
Hood Bay, west coast.

Kosciusko Island.

Davidson Inlet.

Prince of Wales Island.

Karta River, Karta Bay.¹
Whale Passage, behind Thorne Island, northeast coast.
Myrtle Lake outlet, near Niblack post office.
Reynolds Creek, near Coppermount.

¹ Gaging station maintained since January, 1913, by the Speel River project of Juneau.

² Gaging station maintained by U. S. Geological Survey.

Revillagigedo Island.

Orchard Lake outlet, at Shrimp Bay.¹
Beaver Falls, George Inlet.
White River, George Inlet.
Creek, east shore near head of Carroll Inlet.
Fish Creek, Thorne Arm.¹
Gokatchin Creek, Thorne Arm.
Ketchikan Creek, at Ketchikan.¹

Annette Island.

Tamgas Harbor.

TRANSPORTATION.

All the marble properties in southeastern Alaska thus far developed and a great many undeveloped deposits are situated either close to or directly on deep water. At present marble in rough blocks is carried by freight steamers to Tacoma, Portland, and San Francisco. Freight rates have been much reduced in the last few years through competition and are reported to be moderate at present.

COMPETITION.

Considerable marble is still shipped to the Pacific coast from quarries in the eastern United States, mainly Vermont and Tennessee, and some is imported from Italy. The output of Alaska marble is increasing, however, and there is said to be a market for all of it that can be produced. In the western half of the United States marble quarries and prospects have been opened in Stevens County, Wash.; Josephine County, Oreg.; Inyo and Tuolumne counties, Calif.; Cochise County, Ariz.; Otero County, N. Mex.; White Pine County, Nev.; Beaver County, Utah; and Gunnison County, Colo. Only the product of the California and Colorado quarries has been of commercial importance thus far.

In British Columbia large deposits of marble are known along the sounds, on the coast, and in the interior. Among those on Vancouver Island are deposits on Nootka Sound and at Beaver Cove. The deposit on Nootka Sound was once quarried but is reported not to have been operated since 1909. On Malaspina Inlet two small deposits have been noted, one of which is of white marble and the other of gray and white marble, mixed with serpentine. The principal marble quarry in the Province is that of the Canadian Marble & Granite Co., on the Canadian Pacific Railway between Lardo and Trout Lake. This quarry is equipped with finishing works and

¹ Gaging station maintained by U. S. Geological Survey.

supplies the greater part of the marble used in British Columbia. White marble is reported near the town of Wycliffe, on the Kimberly branch of the Canadian Pacific Railway, and dolomitic marble of various colors in the Rocky Mountain region on the slopes of Mount Ogden, 2 miles from the mouth of Yoho River.

It is not likely that during the maintenance of the present tariff on marble much of the Canadian product can be sold profitably within the United States, nor can the Alaskan product be delivered in Canada, although it must pass through Canadian waters on the way to the United States.

PRODUCTION.

According to the Survey records the first marble produced in Alaska was quarried in 1901 by the Alaska Marble Co. at Calder, and the first shipment to the United States was made in 1902. For the years 1902 and 1903 no production was reported, but beginning with 1904 the output has steadily increased year by year. It is not possible to give the statistics of production by years, for in only one year were there more than two reporting producers, and it is the custom of the United States Geological Survey to avoid publishing figures that might reveal individual operations. In all, however, from 1901 to 1919 Alaska producers have reported total shipments of unfinished marble to the United States of an approximate value of \$1,830,000. Not included in this total is a small output of marble used locally for tombstones and monuments.

USES OF ALASKA MARBLE.

Small quantities of marble have been shipped to the United States from the quarries of the Alaska, El Capitan, Mission, and Alaska-Shamrock companies, but by far the greater part of the output has come thus far from the quarry of the Vermont Marble Co. on Marble Island. The product of this quarry is shipped to the electrically driven mill owned by the company at Tacoma, Wash., where the rough blocks are sawed into smaller blocks for turning and planing and into slabs three-quarters of an inch to 1 inch thick for polishing. The slabs and sawed blocks are worked up into wainscotings, ceilings, floor tiles, moldings, fixtures, rails, balustrades, and a variety of forms for interior finish and decoration. The market for these products is principally in the cities of the Pacific Coast States, but it extends as far eastward as the Atlantic seaboard.

In the important buildings listed below (to 1916) marble from Token, Alaska, is reported to have been used in interior work. (See Pls. XXIII-XXV.)

SEATTLE, WASH.

Arctic Club.
Hoge Building.
Lyons Building.
Haight Building.
L. C. Smith Building.
Bank of California Building.
McCormick Hotel.
King County courthouse.

TACOMA, WASH.

National Realty Building.
Perkins Building.
Tacoma Building.

BELLINGHAM, WASH.

United States post office.

NORTH YAKIMA, WASH.

United States Post Office.

WALLA WALLA, WASH.

Walla Walla County Courthouse.

VANCOUVER, B. C.

Pacific Building.
Rogers Building.

VICTORIA, B. C.

Sayward Building.

PORTLAND, OREG.

Spaulding Building.
Wilcox Building.
Yeon Building.
Selling Building.
Littman-Wolfe Building.
Oregon Journal Building.
Multnomah Building.
Stevens Building.

THE DALLES, OREG.

The Dalles County Courthouse.

SAN FRANCISCO, CALIF.

Flatiron Building.
Odd Fellows Building.
Sharon Estate Building.
Hobart Building.

OAKLAND, CALIF.

Federal Realty Building.
Bankers Investment Building.
Realty Syndicate Building.
Oakland Manual Training School.
Harrison Hotel and Apartments.

SACRAMENTO, CALIF.

Capital National Bank Building.
Forum Building.
Travelers Hotel.

FRESNO, CALIF.

Griffith McKenzie Building.
Rowell Building.

LOS ANGELES, CALIF.

Black Building.
Los Angeles Investment Building.
Title Insurance and Trust Building.
Van Nuys Building.
Brockman Building.
Community Mausoleum, Inglewood.
Haas Building.
Hollingworth Building.
Merchants National Bank Building.
Marsh-Strong Building.
Southern Pacific Passenger Station.

SAN DIEGO, CALIF.

Central Mortgage Building.
Spreckels Theater.
United States Post Office.

SANTA ROSA, CALIF.

Community Mausoleum.

PRESIDIO, CALIF.

United States General Hospital.

MODESTO, CALIF.

Community Mausoleum.

HONOLULU, HAWAII.

Pearl Harbor Naval Hospital.

BOISE, IDAHO.

State Capitol.
Gem Building.

MOSCOW, IDAHO.	GREAT FALLS, MONT.
United States Post Office.	Ford Commercial Building.
LEWISTON, IDAHO.	ST. PAUL, MINN.
United States Post Office.	Great Northern Railway Building.
SALT LAKE CITY, UTAH.	PITTSBURGH, PA.
Walker Building.	City and County Building.
National City Bank Building.	PHILADELPHIA, PA.
Empress Theater.	Finance Building.
Newhouse Hotel.	BOSTON, MASS.
OGDEN, UTAH.	Orpheum Theater.
Eccles Building.	

It is also reported that this marble was used in the exterior trim in the front of the Merrill apartments at Seattle, Wash., but that no effort has yet been made to push the use of the stone for such purposes.

The Alaska-Shamrock Marble Co. reports having furnished marble from Dickman Bay for decorative work in the entrance to the Charlotta Court and to the Majestic Theater buildings in Portland, Oreg. (See Pl. XXVI.)

A small quantity of Alaska marble is used locally for monuments, for which it is said to be entirely suitable. A handsome altar in St. Philip's Episcopal Church in Wrangell was fashioned (except the cross) from white marble obtained from Ham Island, Calder, and Token, Alaska. The body of the altar has received a hone finish; the cross, which is of polished Italian marble, is mounted on a base of polished marble from Token. There is apparently no essential difference between these pieces of Italian and Alaskan marble.

IMPORTANT UNDEVELOPED DEPOSITS.

Some of the undeveloped deposits of marble described in this paper (those from which no stone has been quarried) possess elements of possible economic value, but not all of them seem to warrant prospecting, and even those that have appeared most favorable on cursory inspection may prove on prospecting to be totally unfit for exploitation. The more important of these undeveloped deposits, whose surface appearance and general relations suggest that further investigations might be warranted whenever the demand for marble on the Pacific coast exceeds the present production, are mentioned in the following summary:

Limestone Inlet opens directly on one of the highways of travel, Stephens Passage, and is close to a base of supplies at Juneau; therefore, although the surface appearance of the grayish-white and banded medium-grained marble 1 mile above the head of this inlet

(No. 1) does not suggest that stone of the highest quality is present here, the hope of finding a good marble deposit in this advantageous location should encourage more thorough prospecting.

The white and gray fine-grained banded marble in the vicinity of Basket Bay and the neighboring cove to the south, on the Chatham Strait shore of Chichagof Island (Nos. 11, 12, 13), seems promising. There appears to be a very large body of marble in this vicinity, and the larger the deposit the better should be the chances of finding a portion of it workable.

The exposed portion of the deposit of white to white and gray hard medium-grained marble a third of a mile south of Marble Cove, on the Chatham Strait shore of Admiralty Island (No. 17), has a terrace form that suggests a favorable site for a quarry. There is an abundance of timber and fresh water here, and although the harbor near by is small, breakwaters and docks could be constructed that would afford protection and facilities for loading vessels.

In the northern part of Prince of Wales Island, in the vicinity of Red Bay (Nos. 23, 24, 25), a considerable variety of marble is found, mostly of fine grain. Much of this marble is easily accessible, and it is probable that the creek and lake above the head of the bay may be utilized in bringing blocks down to tidewater.

A vast quantity of coarse marble, of a pleasing light grayish-blue shade, is available north of Dry Pass (No. 28). This place, however, is not accessible by ocean-going boats, and marble could be barged down to Shakan Bay only at times of high tide in Dry Pass.

Kosciusko Island, in the vicinity of Edna Bay (No. 32), contains areas of fine-grained, partly metamorphosed limestone of variegated shades and mottled effects, susceptible of high polish, and similar material occurs on the north side of Heceta Island (No. 36).

Dall Island has been shown to contain deposits of beautiful marble on both the west and east coasts, and it is probable that the island has not yet been wholly explored. The most promising deposits seem to be those at Waterfall Bay (No. 37) and at View Cove (No. 39), although there are probably good deposits near other bays on the east side of the island. The fine-grained pink and white mottled marble from Waterfall Bay, as well as the white marble with yellow veinlets, are of the highest quality, and the bluish-gray and black varieties take high rank with commercial marbles of similar shades. At View Cove there are several varieties of attractive marble, including pearl-gray fine-grained rock and rock of black, yellow, and grayish-green shades.

The northern part of Long Island appears to contain promising deposits of marble. On Waters Bay (No. 45) occur attractive white, bluish-white, pearl-gray, gray-veined, and banded marbles, gener-

ally of medium grain, and on Gotsongni Bay (No. 46) there are deposits of medium-grained white, pink and white, and bluish-white and gray marble of good quality. Both of these areas are said to be located favorably for quarrying and shipping.

On the mainland east of Wrangell Island occur some areas of medium to coarse grained white to gray and blue marble that may prove of value. Among them might be mentioned that on Blake Channel near its junction with Eastern Passage (No. 51).

White fine-grained marble of even texture, fairly well situated for quarrying and shipping, occurs on Revillagigedo Island near Carroll Inlet (No. 58).

As to the other undeveloped deposits described in this report less encouragement can be given regarding the possibilities of profitable exploitation under present conditions. For special decorative purposes, where cost is a minor consideration, some very unusually banded marble may be obtained from the schistose deposits on Admiralty Island near Point Hepburn (No. 14) and north of Marble Cove (Nos. 15 and 16), but it is doubtful whether these deposits can be quarried in competition with the more homogeneous calcite marbles already developed. About the shores and islands of Glacier Bay (Nos. 2 to 8) there are indications of an abundance of marble, but it is probable that the remoteness of this bay from settlements, the scarcity of large timber in the vicinity, and the uncertainties of navigation will retard active quarrying there.

PATENT TO MARBLE LANDS.

Government lands that are chiefly valuable for their content of building stone (including marble) may be located as placer claims, and but one discovery of mineral is required to support a placer location. An individual may claim 20 acres, but in Alaska no association placer claim located after August 1, 1912, can exceed 40 acres, irrespective of the number of persons associated together. On every placer-mining claim located in Alaska after August 1, 1912, and until patent therefor has been issued, not less than \$100 worth of labor must be performed on improvements made during each year, including the year of location, for each 20 acres or excess fraction thereof included in the claim. The proof of improvements must show that their value is not less than \$500 and that they were made by the applicant for patent or his grantors. This proof should consist of the affidavit of two or more disinterested witnesses.

The procedure to obtain patent to mineral lands is given in detail in a publication by the General Land Office, Department of the Interior, to which the interested reader is referred.¹

¹ United States mining laws and regulations thereunder: General Land Office Circ. 430, 104 pp., 1915.

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GEORGE OTIS SMITH, Director

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**THE ANVIK-ANDREAFSKI REGION
ALASKA**

(INCLUDING THE MARSHALL DISTRICT)

BY

GEORGE L. HARRINGTON



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THE ANVIK-ANDREAFSKI REGION, ALASKA.

By GEORGE L. HARRINGTON.

FIELD WORK AND ACKNOWLEDGMENTS.

This report is intended to cover the results of the explorations of a United States Geological Survey party during the summer of 1916, in charge of R. H. Sargent, topographic engineer. The writer was attached to the expedition as geologist, C. F. Bailey acted as recorder, and C. E. Anderson as cook.

The party was landed from the steamer at Anvik on June 15, and carried on work from that time until a steamer was boarded at Andreafski on September 13. A 30-foot poling boat equipped with a 2-horsepower engine of the detachable hang-over type was the principal means of transportation throughout the summer. A topographic and geologic traverse was made on the Yukon from Anvik to Andreafski and up Anvik, Bonasila, Stuyahok, and Andreafski rivers as far as was considered practicable under the limitations of the short season. The intervening stretches of country inaccessible from the boat were not visited. In addition to making these traverses along the streams, the party spent 16 days in the vicinity of Marshall in studying the mineral resources and in topographic and geologic mapping.

The writer wishes to express to Mr. Sargent and to each of the members of the party his appreciation of their cordial aid in the furtherance of the geologic work on every possible occasion. To Rev. J. W. Chapman and others at Anvik who assisted in the preparation and equipment for field work the members of the party feel their indebtedness, and to every miner, prospector, and merchant met during the summer thanks are due for the unfailing hospitality, the spirit of ready cooperation, and the unflagging interest in the carrying on of the Survey work. Such assistance made doubly efficient the efforts of the members of the party where reliance had to be placed on other than their own efforts or equipment for the prosecution of the work.

In the office the members of the division of Alaskan mineral resources have rendered assistance in many ways, and the writer is

especially indebted to H. M. Eakin and A. G. Maddren, whose work in near-by provinces has elucidated obscure physiographic and geologic problems in this region. Grateful acknowledgments are made to J. B. Mertie, jr., for assistance in making petrographic determinations. F. H. Knowlton and J. B. Reeside, jr., determined the fossil collections obtained during the summer.

EARLY HISTORY AND PREVIOUS WORK.

Although the coast of Alaska had been early explored by the Russian and English navigators, the interior country was wholly unknown, even after a considerable trade in furs had been established along the coast. Of the many who explored the Yukon, Glazanof¹ appears to have been the first. He reached Anvik from St. Michael early in 1834, crossing the portage with dogs. After crossing to the Kuskokwim, he returned to the Yukon and apparently reached St. Michael by way of the mouth of the river. He was followed in 1838 by Malakof, who crossed by the Unalaklik portage and ascended the Yukon as far as the mouth of the Koyukuk. The next summer he reached the mouth of the river by boat. In 1842 Lieut. Zagoskin, of the Imperial Russian Navy, traversed the river from its mouth to the vicinity of Nulato, and in 1844 he reached the mouth of the Nowitna. He prepared a map, which accompanies the report of his explorations.²

The earliest geologic work in this portion of Alaska was done by W. H. Dall in 1866 to 1868, while he was in charge of the scientific corps of the Western Union Telegraph Co.'s expedition. He made a traverse from Fort Yukon to the mouth of the river in 1867, and again went down the river from Nulato to St. Michael the following summer collecting geologic and other scientific data. His narrative³ contains a map and some geologic notes, but more detailed information is to be found in other reports⁴ of a more technical character.

Whymper was an associate of Dall and the artist of the telegraph expedition. He assisted in gathering data which were doubtless used in the preparation of his own book⁵ and that of Dall. A map of the Yukon and a small-scale map of Alaska are included in his account of his travels with Dall.

¹ Brooks, A. H., unpublished manuscript.

² Zagoskin, L., *Travels on foot and description of the Russian possessions in America, from 1842 to 1844*, St. Petersburg, 1847 (in Russian); also in German in *Erman's Archiv für wissenschaftliche Kunde von Russland*, vols. 6 and 7.

³ Dall, W. H., *Alaska and its resources*, 1870.

⁴ Dall, W. H., and Harris, G. D., *Correlation papers, Neocene*: U. S. Geol. Survey Bull. 84, pp. 232-268 and map, 1892. Dall, W. H., *Report on coal and lignite of Alaska*: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 763-908, 1896; *Boston Soc. Nat. Hist. Proc.*, vol. 12, p. 128, 1869; *Exploration in Russian America*: *Am. Jour. Sci.*, 2d ser., vol. 45, pp. 97-99, 1868.

⁵ Whymper, Frederick, *Travel and adventure in the Territory of Alaska, 1869*.

Upon the acquisition of the territory by the United States, one of the questions to be settled was whether the Fort Yukon post of the Hudson Bay Co. was on American or Canadian soil. To determine this point the first of the expeditions under the auspices of the United States Army into interior Alaska was undertaken in 1869 by Capt. Raymond.¹ His party, consisting of himself, John J. Major, and Pvt. Michael Foley, obtained passage on the small steamer *Yukon* on its first trip up the river. Observations were taken at St. Michael, Anvik, Nulato, and Fort Yukon to determine their position. Assisted by Major, he made a traverse of the river while ascending it, using the time and compass method. After observations had been made at Fort Yukon, the party descended the river in a small boat and crossed to St. Michael by the Anvik portage. The results of Raymond's surveys appear on the map compiled by him and included in his report.

The party of Lieut. Schwatka² made a military reconnaissance of the Yukon in 1883, and Charles Homan, attached to the party as topographer, made a topographic sketch map of the region.

Russell³ was the first geologist detailed by the United States Geological Survey to make studies in the Yukon Valley. In 1889 he accompanied the Coast and Geodetic Survey parties that determined the location of the international boundary where it crosses Yukon and Porcupine rivers. From the nature of his trip he was afforded but scanty opportunity for making geologic studies on the lower Yukon, but his report contains many significant facts regarding physiographic features.

With the development of gold mining in Alaska parties were sent by the Geological Survey to investigate the mineral resources and to make surveys in the producing regions. In 1896 such a party, in charge of J. E. Spurr, with H. B. Goodrich and F. C. Schrader as geologic assistants, undertook the study of the mining camps in the interior. They descended the Yukon from its source to its mouth, investigating on the way the Fortymile and Birch Creek districts and making extensive studies⁴ along the river as far down as Nulato. A small-scale map⁵ of the lower Yukon accompanies the report of this investigation. From information obtained on this trip and on a trip made in 1898 a geologic reconnaissance map of south-

¹ Raymond, C. W., Report of a reconnaissance of the Yukon River, Alaska Territory, 42d Cong., 1st sess., S. Ex. Doc. 12, 1871.

² Schwatka, Frederick, Report of a military reconnaissance in Alaska made in 1883, 48th Cong., 2d sess., S. Ex. Doc. 2, 1885.

³ Russell, I. C., Notes on the surface geology of Alaska: Geol. Soc. America Bull., vol. 1, pp. 99-162, 1890.

⁴ Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 8, pp. 87-392, 1898.

⁵ Idem, p. 190.

western Alaska was prepared.¹ A map of the Kuskokwim-Yukon portage² was compiled from notes taken by F. C. Hinckley, one of Spurr's assistants, who crossed to the Yukon by way of the portage and thence down the Yukon to St. Michael.

In 1902 Collier³ spent the season in an investigation of the coal resources of the interior of Alaska. Sidney Paige assisted him and made a canoe traverse from Eagle to Paimiut. Collier's report contains a map⁴ showing the distribution of the coal-bearing terranes in the Yukon Valley. The base map is a compilation of previous surveys but includes also the results of Collier and Paige. In addition to gathering data regarding coal, Collier made extensive geologic notes which have been available to the writer in the preparation of this report. In order to make stratigraphic and paleontologic studies Arthur Hollick, with Sidney Paige as his assistant, revisited in 1903 the localities from which fossils had been obtained by earlier geologists. The results of their collecting have been available to later investigators and are being utilized in the preparation of the monographs by Hollick on Alaskan Cretaceous and Tertiary floras.

In 1907 W. W. Atwood, with H. M. Eakin as his assistant, undertook further studies and descended the Yukon as far as Holy Cross, where the season's work was closed. The following year Maddren⁵ spent a portion of the field season in a study of the Innoko placers and made material contributions to the existing knowledge of the geology of the lower Yukon region. Maddren's explorations were followed in 1909 by the expedition of Smith and Eakin⁶ between Nulato and Norton Bay and in southeastern Seward Peninsula. The results of these expeditions are of great value in the interpretation of the geology of the areas lying south and southwest of the regions traversed by them, but large areas that are geologically unexplored lie between the areas previously surveyed and that mapped in 1916.

The Marshall district had not previously been visited by any member of the Geological Survey, but notes on the mining operations on Wilson Creek and on the general conditions in that vicinity were obtained by H. M. Eakin in 1914⁷ and by A. H. Brooks in 1915.⁸

Besides the investigations by the parties of the Geological Survey work has been done by members of the Coast and Geodetic Survey

¹ Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 234, 1900.

² Idem, p. 98.

³ Collier, A. J., The coal resources of the Yukon, Alaska: U. S. Geol. Survey Bull. 218, 1903.

⁴ Idem, p. 10.

⁵ Maddren, A. G., The Innoko gold placer district, Alaska: U. S. Geol. Survey Bull. 410, 1910.

⁶ Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449, 1911.

⁷ U. S. Geol. Survey Bull. 622, pp. 65-68, 1915.

⁸ U. S. Geol. Survey Bull. 642, pp. 67-68, 1916.

in this and adjoining regions. Commencing in 1898 and extending over the following season, several parties were engaged in charting the shores off the Yukon delta, the mouths of the river, and the main river as far as Andreafski.¹ The work along the river and the shores of Norton Sound was controlled by triangulation and includes some topographic as well as hydrographic mapping. The work of the Geological Survey party in 1916 was done in an area adjoining that covered by the earlier work of the Coast and Geodetic Survey parties, of which a portion has been used in the preparation of the accompanying topographic map (Pl. I).

In 1908 a series of magnetic stations along the Yukon were occupied by J. W. Green, of the Coast and Geodetic Survey, and magnetic and astronomic observations for latitude and longitude were made in the region covered by this report at Anvik, Holy Cross, Russian Mission, and Andreafski.

GEOGRAPHY.

LOCATION.

The Anvik-Andreafski region as described in this report embraces the territory west and north of the lower Yukon River between Anvik and Andreafski rivers and an extensive area of low-lying country immediately contiguous to the Yukon on its east and south sides. Extending from longitude $159^{\circ} 40'$ to $163^{\circ} 20'$ W. and from latitude $61^{\circ} 30'$ to $63^{\circ} 40'$ N., the area covered by the surveys in 1916 is approximately 2,000 square miles. The map of the Marshall mining district (Pl. II, in pocket) covers the area in which mining is being done.

NOMENCLATURE.

The history of the Anvik-Andreafski region throws light on the source of the names of the towns and topographic features. These names are in part in the tongue of the two native races that first inhabited the region. Later the Russian language furnished some names, and the advent of men of English-speaking races brought about other changes, modifying some of the earlier names and substituting new names for others.

So far as possible the names in most common use have been employed on the topographic maps (Pls. I and II, in pocket) and in this text. If both native and English names are known and both appear to be used to about the same extent, the native name is given preference. For a list of the names of the natural features in the vicinity of Marshall, many of them applied by the natives, the survey is indebted to Mr. Frank Waskey.

¹ Coast and Geodetic Survey chart 9370, Cape Romanzof to St. Michael, Alaska.

In naming some of the creeks the English-speaking miners have exhibited the same poverty of vocabulary or lack of originality that is to be found in many other mining districts. The repetition of the commoner names for creeks, such as Spruce, Willow, Bear, and Flat, in almost every district in Alaska leads to such confusion that in order to be clearly understood it is frequently necessary to refer not only to the district in which the creek is found but to the larger stream to which the particular creek is tributary. It may even be necessary to name a third or a fourth stream into which the smaller one flows in order to make identification positive. It would seem to be false modesty which inhibits the discoverer of a creek from naming it after himself. His name applied to it usually has the double advantage of giving it individuality and of having historic value.

RELIEF.

GENERAL CHARACTER.

In general, the relief of the region is slight. The highest point attains an altitude of about 2,700 feet, and there are comparatively few small isolated areas lying above 2,000 feet. Along the west and north bank of the Yukon the surface is in places sharply dissected, but as a whole the forms are those of a mature topography, so that the country presents a rolling aspect. Wide, poorly drained lowlands occupy the intermontane areas.

UPLANDS.

The uplands are scarcely high enough to merit the term mountains, although here and there a point rises well above the general level and furnishes a conspicuous and easily identified landmark. Of this character are Bonasila Dome, Chiniklik, and Pilcher Mountain.

Bonasila Dome lies east of Stuyahok River and south of Bonasila River, and its isolation, together with its peculiar form (a cone on the crest of a gently crowning dome), gives it prominence from whatever point it is seen. It is sometimes called Simel Mountain.

The highest and most conspicuous peak in the region is that known by the guttural native name of Chiniklik, frequently corrupted by the whites to Cheneegly. It appears remarkable that so high a peak should be only 4 miles from the Yukon. It lies 8 miles above Russian Mission and 12½ miles below Tuckers Point. This mountain was seen from points along Anvik River, from Andreafski, and from practically all the intermediate stations except those at the water's edge on the banks of the Yukon. Its conical outline, with shoulders a few hundred feet below the apex, readily identifies it. This peak

is visible from many points along the crest of the divide between the Yukon and Andreafski drainage basin and from points far south of the Kuskokwim.

Pileher Mountain lies about 5 miles east of Marshall. It rises well above the immediately adjacent hills, and is topographically prominent because of the exceptionally well-developed altiplanation terraces on all sides but the southeast.

The areas occupied by the softer sedimentary rocks of Mesozoic age are everywhere, except near the Yukon, marked by the gentle slopes and rounded crests that are characteristic of a mature topography. Elsewhere the drainage is that of an area past maturity in the cycle of erosion, but the crests of the hills present a terraced appearance (Pl. V, B, p. 22). The origin of these forms has been described by Eakin,¹ who termed the process altiplanation. This feature is discussed further in connection with the Quaternary history (p. 55). The terraces are best developed in the areas of igneous rocks at the higher elevations. To a minor degree altiplanation has taken place in some areas of the more indurated sedimentary rocks, especially in the vicinity of intrusives.

LOWLANDS.

The lowlands may be subdivided into two classes—those that lie above the flood level of the Yukon and those that are reached by its highest stages of water. The lowlands of the first class occupy the broad erosional depressions that are characteristic of the region. Bedrock crops out along the streams only here and there—not at all for several miles above their mouths. Alluviation has proceeded so far that, except in their headward portions, the streams flow in meandering courses along which are many oxbow sloughs formed by abandoned meanders. In the lowlands that lie within the influence of the Yukon are to be placed the wide stretches which extend to the Kuskokwim east and south of the Yukon. On the larger tributary streams alluviation has lowered stream gradients to such an extent that they are controlled by the Yukon at all but the lowest stages. Five miles up the Bonasila the writer saw débris which undoubtedly came from the Yukon. It is therefore conceivable and even probable that the alluvial material that is now being laid down over the bottom lands along the lower reaches of this and other tributaries is derived in large part from the overloaded flood waters of the Yukon, which deposit a considerable portion of their burden in the slack waters of the embayments furnished by these stream mouths.

¹Eakin, H. M., The Yukon-Koyukuk region, Alaska: U. S. Geol. Survey Bull. 681, p. 78, 1916.

DRAINAGE.

To the geologic structure was due the original position and direction of many of the streams, but other factors have affected their later history, and the former courses have been somewhat modified by alluviation and lateral erosion. The valley occupied by Stuyahok, Bonasila, and Anvik rivers affords an excellent example of stream trend initially controlled by the underlying bedrock structure, and the Yukon above Holy Cross trends in the same general direction. Structural control is also evident in the vicinity of Marshall and, at least in part, along the north fork of Andreafski River.

The region considered in this report lies wholly within the Yukon drainage basin, but the wide, flat, lake-dotted delta between the Kuskokwim and the Yukon, opposite and below Russian Mission, has so little relief that the watershed between the two rivers is difficult of location. So far as could be ascertained, there are few places, except near the coast, that rise even so high as 100 feet above either of the rivers. At high stages of water much of this lowland is inundated. During the spring of 1916 the small steamer *Tana* left the Yukon through a slough near Pilot station and, entering Kashunuk River, reached Bering Sea through Hazen Bay. Essentially similar conditions are to be found in the delta of the Innoko. At high water this river may be reached through any one of several mouths, from a point several miles above Anvik to the last slough, about 11 miles below Paimiut. Other tributaries of the Yukon enter from the west and north after passing through considerable delta areas, which are modified by overflow from the Yukon and truncation of their fronts by that river. Bonasila, Koserefski, Kuyukutuk, and Chvilnuk rivers and many of the smaller creeks enter the Yukon through sloughs. Lakes are characteristic of the flood plains of some of these streams throughout their lower reaches and were especially noted in the broad depression occupied by Kuyukutuk and Chvilnuk rivers, which resembles in this regard the region between the Yukon and the Kuskokwim.

CLIMATE.

The climate of the Anvik-Andreafski region is intermediate in character between that of the upper Yukon and the coastal region from Norton Sound to Bristol Bay. The proximity of Bering Sea has a stabilizing influence, so that the summer temperatures are not so high nor, as a rule, the winter temperatures so low as those of the upper Yukon, although north winds may occasionally bring about similar conditions in the two areas. From the records the precipitation appears to be greater in this region than at coast points and almost double that of points in the upper Yukon Valley. In any two consecutive seasons there is likely to be considerable difference in

the amount of rainfall and in the times when precipitation takes place, but normally the greatest precipitation occurs after the middle of July. In 1916 records were kept from June 15 to September 10, inclusive. In the 40 days from June 15 to July 25 there was some precipitation on 21 days, or 52 per cent. In the 48 days from July 25 to September 10 there was some precipitation on 35 days, or 73 per cent.

Meteorologic observations are available for Holy Cross, the only station within the region at which records have been kept for any great length of time, but for comparison records are given for Tanana and Nome also in the following tables, compiled from data obtained from the United States Weather Bureau. Figures in the first three columns are for 1915 only. The other columns are a summary of observations extending over several years.

Records of temperature at Holy Cross compared with those at Nome and Tanana in degrees Fahrenheit.

	Highest in 1915.	Lowest in 1915.	Annual mean 1915.	Highest recorded.	Lowest recorded.	Mean of three sum- mer months.	Mean of three win- ter months.
Nome.....	72	-36	.....	78	-36	40 to 50	10 to 0
Holy Cross.....	81	-43	29.4	84	-57	50 to 55	0 to -10
Tanana.....	89	-48	25.2	90	-76	Over 55	-10 to -15

Dates of last freezing temperature in spring and first freezing temperature in autumn at Nome, Holy Cross, and Tanana, 1915.

	Last in spring.	First in au- tumn.
Nome.....	June 9	Aug. 21
Holy Cross.....	May 12	Sept. 9
Tanana.....	June 5	Aug. 29

Precipitation at Nome, Holy Cross, and Tanana.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	An- nual.
Nome.....	0.87	0.69	1.13	0.43	0.70	0.85	1.21	2.83	2.10	1.27	0.67	1.07	14.82
Holy Cross.....	1.63	1.07	1.54	.56	.31	1.45	2.15	3.54	2.68	1.54	1.32	1.78	19.57
Tanana.....	.77	.62	.61	.20	.96	.73	2.01	2.42	1.18	1.04	.79	.65	11.97

Records of the time of opening and closing of the Yukon at Holy Cross have been kept for a considerable number of years, and there is probably normally very little difference between the dates at this point and others as far down the Yukon as Andreafski. These dates may be summarized as follows:

Ice began to run in spring between April 29 and June 1.

River clear of ice between May 21 and June 3.

Ice began to form in autumn between October 5 and October 16.

River closed between October 19 and November 3.

The rains are usually brought by southerly winds, and northerly winds prevail during periods of fair weather. The southerly winds are frequently of such force as to impede navigation seriously, as the steamboats are likely to be driven aground on some of the numerous bars of the river, and the seas caused by the wind make navigation dangerous for any small boat except a dory or one of the skin boats of the natives. The activity of the wind as an erosive agent was observed many times on the sand bars in the river, for as soon as the surface became dry the sand would drift before the wind and pile up in small irregular hummocks or dunes. Cross sections of dunes thus formed are exposed here and there in the cut banks of the Yukon.

VEGETATION.

Within the area crossed by the expedition of 1916 the conditions affecting vegetal growth are so diverse that a corresponding diversity of plant types is reasonably to be expected. In the vicinity of Anvik the lowlands are well timbered, although an approach to the tundra conditions found below Andreafski is presaged by the lowering of timber line compared with upper-river points. In the vicinity of Anvik, timber line is about 600 to 800 feet above the river, though in favorable localities, such as sheltered, well-drained valleys, it extends somewhat higher. No spruce was seen growing on the Yukon below Andreafski, but scattered stumps of spruce and an occasional straggling birch indicate a former scanty growth of these trees to elevations from 100 to 200 feet above Andreafski River. From the hills back of Andreafski small patches of spruce may be seen scattered through the cottonwood and willow thickets that extend along the Yukon above this point. The best growths of spruce are found along gullies, on slight eminences in the lowlands, or near the banks of streams. Farther back from the smaller streams in the lowlands, where drainage is poor, the growth is usually scattered and stunted. Wherever spruce is found on well-drained hill slopes, birch generally occurs also, together with small-leaved poplar or quaking aspen. Extensive growths of these trees are apparently less common than in the Tanana basin. On Anvik and Bonasila rivers the birch bark is used by the natives in making their canoes. Tamarack grows in very open groves in the more boggy places along the Anvik and Bonasila and was seen here and there along the Yukon.

Throughout the lower-lying portions of the area, cottonwood and several species of willow constitute the most common element of the forests. Some of the bars that have barely emerged from the river are covered with a dense growth of willows a few inches high.

In the driftwood along the river there appears to be less willow and cottonwood than spruce. From this it would seem that a con-

siderable amount of the drift has come from points farther up the river, where the proportion of spruce is greater than it is within the Anvik-Andreafski region. It is probable, however, that the preponderance of spruce in the driftwood may be due partly to the fact that it rots less easily and is not so quickly waterlogged.

Alders are found throughout the region at considerably higher elevations than any timber trees. They cover the slopes, in places occurring almost at the crests of the hills or ridges, where some protection is afforded by the depressions in the headward portions of the streams.

Berries of some variety can be found in almost any part of the region. Blueberries are common on the fairly open slopes. Low-bush cranberries are found with them or at somewhat higher elevations and where there is little or no brush. The soft yellow salmonberry appears to grow at almost any elevation but seems to be most abundant in situations less well drained than those occupied by the other berries. The bitter high-bush cranberry was found in shady places along the river bank associated with red and black currants, which were also found on the drier, sunny slopes, together with red raspberries. Neither currants nor raspberries were seen in abundance anywhere.

Grasses are surprisingly plentiful in variety and amount everywhere in the region, so that horse feed could easily be obtained for outfits traveling by pack train, especially along the tributaries of the Yukon. On the Stuyahok there are many beautiful open parks containing luxuriant growths of grass, and at almost every point where a stop was made there was an abundance of forage. On the hilltops and most of the slopes a large part of the vegetal covering consists of mosses and lichens, but considerable horse feed is still to be found even here. On the river bars there is usually an abundance of the variety of Equisetum called mare's-tail, and occasionally the pea vine is found.

Horse feed

When the party left the field (September 13) there had been no frosts of sufficient severity to destroy the nourishing qualities of the grasses, but the season of 1916 was probably exceptional in this respect, and killing frosts may ordinarily be expected early in September.

Fairly extensive agricultural operations have been carried on for a number of years by the mission at Holy Cross. The native grasses in natural meadows on the flood plain of the Yukon below the mission are cut and cured for forage or are utilized as pasture. A considerable variety of vegetables are grown for private use. Any surplus is sold and finds a ready market along the river. At Anvik some gardening is done, and several varieties of vegetables mature. The

season without frost appears to be slightly longer here than farther up the Yukon. Along the lower course of Anvik River are grass-covered areas almost wholly free from brush or timber. These natural meadows could doubtless be used for pasture or the grass cut for hay. Similar areas were seen on some other streams, but there appear to be few along the Yukon.

An attempt was made to procure a representative collection of flowers and grasses, so far as other work permitted, but no large shrubs or trees were obtained. The collection was submitted to the United States National Museum, and the following species were identified, the grasses by Mrs. Agnes Chase, the Pteridophyta by William R. Maxon, and most of the other specimens by Paul C. Standley:

FUNGUS.	POACEAE.
<i>Sphacelotheca hydropiperis borealis</i> Clinton (on <i>Bistorta plumosa</i> (Small) Greene).	<i>Alopecurus alpinus</i> J. E. Smith. <i>Calamagrostis canadensis</i> (Michaux) Beauvois. <i>Festuca altaica</i> Trinlin. <i>Poa compressa</i> Linné.
LICHENS.	CYPERACEAE.
<i>Cladonia uncialis adunca</i> (Acharius Flotow. <i>Cladonia deformis extensa</i> (Hoff- mann) Wainio.	<i>Carex canescens</i> Linné. <i>Eriophorum angustifolium</i> Roth.
MOSSES.	MELANTHACEAE.
<i>Drepanocladus uncinatus plumosus</i> (Bruch and Schimper) Roth. <i>Polytrichum commune</i> Linné (near var. <i>uliginosum</i> Hübener). <i>Polytrichum commune</i> Linné. <i>Polytrichum strictum</i> Banks. <i>Sphagnum fimbriatum</i> Willson.	<i>Tofieldia coccinea</i> Richardson. <i>Tofieldia palustris</i> Hudson.
POLYPODIACEAE.	JUNCACEAE.
<i>Dryopteris dilatata</i> (Hoffmann) Gray. <i>Dryopteris dryopteris</i> (Linné) Britton. <i>Dryopteris fragrans</i> (Linné) Schott.	<i>Juncoides</i> sp.
EQUISETACEAE.	IRIDACEAE.
<i>Equisetum arvense</i> Linné. <i>Equisetum sylvaticum</i> Linné.	<i>Iris setosa</i> Pallas.
LYCOPODIACEAE.	SALICACEAE.
<i>Lycopodium annotinum</i> Linné. <i>Lycopodium complanatum</i> Linné.	<i>Salix phlebophylla</i> Andersson.
	RETULACEAE.
	<i>Betula rotundifolia</i> Spach.
	POLYGONACEAE.
	<i>Bistorta plumosa</i> (Small) Greene. <i>Bistorta vivipara</i> (Linné) S. F. Gray.

Polygonum alaskanum (Small) Wight.
Rumex occidentalis S. Watson, form.

PORTULACACEAE.

Caytonia sarmentosa C. A. Meyer.

ALSINACEAE.

Arenaria arctica Steven.
Cerastium alpinum Linné.
Merckia physodes Fischer.
Moehringia lateriflora (Linné) Fenzl.

RANUNCULACEAE.

Aconitum delphinifolium De Candolle.
Anemone narcissiflora Linné.
Anemone richardsoni Hooker.
Batrachium aquatile (Linné) Wimmer.
Caltha palustris arctica (R. Brown) Huth.
Ranunculus reptans Linné.
Ranunculus sp., perhaps a new species.
Thalictrum sparsiflorum Turczaninow.

PAPAVERACEAE.

Papaver nudicaule Linné.

BRASSICACEAE.

Arabis lyrata intermedia (De Candolle) Wight.
Barbarea barbarea (Linné) MacMillan.
Cardamine pratensis Linné.
Draba borealis De Candolle.
Radicula palustris (Linné) Moench.

CRASSULACEAE.

Rhodiola alaskana Rose.

PARNASSIACEAE.

Parnassia kotzebuei Chamisso.
Parnassia palustris Linné.

SAXIFRAGACEAE.

Saxifraga hirculus Linné.
Saxifraga nelsoniana Don.
Saxifraga serpyllifolia Pursh.
Saxifraga spicata Don.

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GROSSULARIACEAE.

Ribes hudsonianum Richardson.
Ribes laxiflorum Fischer.

ROSACEAE.

Argentina anserina (Linné) Rydberg.
Comarum palustre Linné.
Dryas octopetala Linné.
Potentilla nivea Linné.
Potentilla villosa Pallas.
Rosa acicularis Lindley.
Rubus arcticus Linné.
Rubus chamaemorus Linné.
Sanguisorba sitchensis C. A. Meyer.
Spiraea steveni (Schneider) Rydberg.

FABACEAE.

Lathyrus palustris Linné.
Lupinus arcticus S. Watson.
Oxytropis nigrescens (Pallas) Fischer.

GERANIACEAE.

Geranium erianthum De Candolle.

VIOLACEAE.

Viola biflora Linné.
Viola langsдорffii Fischer.
Viola palustris Linné.

ONAGRACEAE.

Chamaenerion angustifolium (Linné) Scopoli.
Chamaenerion latifolium (Linné) Sweet.
Epilobium davuricum Fischer.

APIACEAE.

Bupleurum americanum Linné.
Cicuta douglasii (De Candolle) Coulter and Rose.

CORNACEAE.

Cornus canadensis Linné.
Cornus stolonifera Michaux.
Cornus suecica Linné.

PYROLACEAE.

Moneses uniflora (Linné) Gray.

ERICACEAE.

- Ledum decumbens* (Aiton) Loddiges.
Loiseluria procumbens (Linné) Des-
 vaux.
Phyllodoce caerulea (Linné) Grenier
 and Godron.
Therorhodion glandulosum Standley.

VACCINIACEAE.

- Oxycoccus oxycoccus* (Linné) Mac-
 Millan.
Vaccinium caespitosum Michaux.
Vaccinium vitis-idaea Linné.

DIAPENSIACEAE.

- Diapensia lapponica* Linné.

PRIMULACEAE.

- Tridentalis europaea arctica* (Fischer)
 Ledebour.

GENTIANACEAE.

- Gentiana glauca* Pallas.

POLEMONIACEAE.

- Polemonium acutiflorum* Willdenow.
Polemonium humile Willdenow.

BORAGINACEAE.

- Mertensia paniculata* (Aiton) Don.

MENTHACEAE.

- Mentha canadensis borealis* (Michaux)
 Piper.

SCROPHULARIACEAE.

- Castilleja pallida* (Linné) Kunth.
Castilleja tristis Wight.

- Pedicularis arctica* R. Brown.
Pedicularis capitata Adams. *like Ind. w. gray*
Pedicularis labradorica Panzer. "
Pedicularis langsdoftii Fischer.

LENTIBULARIACEAE.

- Pinguicula villosa* Linné.
Utricularia vulgaris Linné.

RUBIACEAE.

- Gallium boreale* Linné.

CAPRIFOLIACEAE.

- Linnaea borealis* Linné.
Viburnum pauciflorum Pylae.

VALERIANACEAE.

- Valeriana capitata* Pallas.

CAMPANULACEAE.

- Campanula lasiocarpa* Chamisso.

CICHORIACEAE.

- Hieracium triste* Willdenow.
Taraxacum ceratophorum (Ledebour)
 De Candolle.

ASTERACEAE.

- Achillea borealis* Bongard.
Arnica lessingii (Torrey and Gray)
 Greene.
Artemisia arctica Lessing.
Artemisia tilesii Ledebour.
Aster sibiricus Linné.
Senecio resedifolius Lessing.
Solidago lepida De Candolle.
Solidago multiradiata Aiton.

ANIMAL LIFE.

Animal life is abundant, but there is little large game. Only one small black bear was seen, but the tracks of black bear were fairly common along the sand bars, and brown bear were reported. Neither caribou nor moose were seen, and it is said that there are none in this part of Alaska. Their former presence in great numbers is recorded

by the earlier explorers, and on some of the ridges their trails are still visible. Domesticated reindeer are herded in the southern part of the region and small bands are pastured near Marshall and Andreafski.

Of smaller animals a few rabbits and foxes were seen. The tracks of the foxes were frequently observed along the river bars, where they had been stalking the aquatic birds. Beaver dams and houses were seen on the Stuyahok, and there was also evidence of the presence of ermine, mink, marten, and muskrats on this and other streams. To judge from their tracks, porcupines are fairly common. The red-backed mouse was frequently observed.

Ducks were seen almost constantly on the streams tributary to the Yukon. Geese were abundant on the Stuyahok and lower Bonasila, and in the fall they were seen in flocks of hundreds on Yukon and Andreafski rivers. Large flocks of ducks were also seen on the Andreafski, as well as smaller flocks of swans and cranes. Near the banks of the rivers some individuals of the several species of sandpipers, snipe, and plover were almost always in sight, busily engaged at the water's edge in search for food.

The land game birds were exceptionally scarce. Ptarmigan were seen but twice, and only one grouse was seen during the summer. Other birds noted include loon, tern, gulls of several species, horned owl, hawks of several species, kingfisher, raven, three species of swallows, junco, three species of sparrows, varied thrush, hermit thrush, robin, warblers, waxwing, Canada jay, and shrike.

On clear-water streams that had a good current grayling were taken with a fly, and no difficulty was experienced in getting as many as were desired. Occasionally a trout was caught, but the trout seemed less numerous than the grayling. Fish wheels and fishtraps are used on the Yukon for catching salmon and whitefish. The salmon are smoked and dried or salted down to be eaten during the winter, by dogs as well as men. The whitefish are used largely as summer feed for the dogs. Trout, pike, and pickerel are also said to be taken by fish wheels or in nets. Considerable quantities of fish of various kinds are caught in large dip nets, which are handled with consummate skill by the natives. In winter whitefish are caught through holes in the ice by the natives, who use for bait an artificial minnow made of bone or ivory.

On Bonasila River large areas were noted where the willows and alders along the banks had been almost entirely stripped of their foliage by small worms, probably the larvae of a small black and white butterfly which was especially common. In places also the willows were infested with small black weevils, which were doing considerable damage.

SETTLEMENTS AND POPULATION.

A certain proportion of Alaska's inhabitants may be termed literally a "floating" population, and for many of them, both whites and natives, the act of changing their abodes in summer consists in loading their few necessities into boats of some description and traveling by water to places where employment may be had or where there exist more favorable conditions for obtaining food by hunting or fishing. A great number of the natives live in temporary fishing camps during the summer but assemble into villages in the winter. The population of many a mining camp is evanescent, and winter finds the workers greatly diminished in numbers, the quondam miner having become a prospector or trapper and sought other scenes for his activities, or he may have left Alaska for the winter, to return in the spring. The following statements as to the population of the Anvik-Andreafski region should be considered with these general conditions in mind.

There are permanent white residents at Anvik, Holy Cross, Marshall, and Andreafski, and a few others have trading posts or fishing stations at other points on the Yukon. There are also white teachers at Pilot station and Russian Mission. On Anvik, Bonasila, and Stuyahok rivers are cabins which are used in winter by prospectors and trappers. It is said that cabins have also been built for winter use on the Kuyukutuk, Chvilnuk, and Andreafski. Marshall is the point of transfer for the supplies for the mining camp on Willow Creek, about $7\frac{1}{2}$ miles away, which is the largest center of population in the region. In August, 1916, none of the cabins on Wilson Creek, which lies between Willow Creek and Marshall, were occupied, although considerable mining had been done on its tributaries earlier in the season. The white population at Marshall and on Willow Creek in 1916 was about 225 and at all other points from Anvik to Andreafski, including these villages, about 35, a total of 260.

The natives are of two stocks. Those above Paimiut are affiliated with the Athapascans of the upper Yukon. Those at and below Paimiut are affiliated with the natives of the coast but show slight differences in dialect. At each of the towns in the region except Marshall the natives are more numerous than the whites. Many native villages are scattered along the Yukon, some of which are temporary and some permanent, having solidly constructed log houses, caches, and drying houses for the summer catch of salmon. There are no permanent native villages in the mountainous country on the west and north bank of the Yukon. Ruins of old deserted villages were seen on the Anvik, and early in the spring the natives make a trip up this river to fish and to build boats, but nothing like a permanent camp was seen. It is said that the natives also fre-

quently make portages from the head of Mountain Creek to the headwaters of the Stuyahok to fish and trap on that stream, and they then drift down to the Bonasila and the Yukon to avoid the return portage. The native population includes about 200 at Anvik and along the Yukon between Anvik and Holy Cross, 200 at Holy Cross, and 300 in the Innoko delta. Between Holy Cross and Russian Mission there are about 70 natives, mostly at Paimiut. There are 150 at Russian Mission and in the villages between Russian Mission and Marshall. About 750 make their homes in the area between Marshall and St. Michael, and of these perhaps 120 are at Marshall and Andreafski and between these two villages. The total native population in the Anvik-Andreafski region is nearly 1,000, of which about 700 are of the upper river race and the others belong to the lower river or coast stock.

Schools have been established at many of the villages. Those at Anvik and Holy Cross are sectarian, and most of their students live in the school dormitories. Government schools are maintained at Russian Mission, at Pilot station, and in the Innoko delta at Shageluk. Two Government teachers are also attached to the mission school at Holy Cross.

COMMUNICATION.

In summer practically the entire region is accessible by boat. Steamboats afford a ready means of transportation on the Yukon and are run at intervals of a week to 10 days. On the Bonasila there is sufficient depth of water for steamboat navigation to the mouth of the Stuyahok, where soundings gave a depth of 13 feet. All the larger streams are navigable by poling boats or small launches for considerable distances from the Yukon. The Survey party in 1916 used a 30-foot poling boat equipped with a 2-horsepower engine of the detachable type. The boat usually carried a load of nearly a ton but experienced little difficulty in ascending the streams that were traversed and made good progress up the Yukon. An engine of higher power, however, is to be recommended for a boat and load of this size. A boat with greater freeboard than a poling boat is also desirable for use on the Yukon.

During the summer of 1916 a wireless station was erected at Holy Cross by the Signal Corps of the United States Army. This is the only telegraph station within the region, but there are stations at Nulato, Kotlik, and St. Michael.

During the summer there is a weekly mail service on the Yukon and throughout the year a monthly service between points on Kuskokwim River and on the Yukon to and above Russian Mission. During the period when navigation is closed there are five mails from St. Michael to Marshall (Fortuna Ledge post office) and intermediate points.

DESCRIPTIVE GEOLOGY.

GENERAL FEATURES.

The principal rocks of the Anvik-Andreafski region are distributed essentially as indicated on the geologic maps (Pls. III and IV, in pocket). Much the same conditions prevail in this region as in many other parts of the Yukon basin, so that, although the general distribution of the several units is ascertainable, their exact boundaries are not readily determined. Contacts are almost universally obscured by Quaternary alluvium or by a mantle of residual material, produced by mechanical and chemical disintegration, which migrates down the slopes and effectually conceals the distribution of the underlying rocks. Comminuted rock *débris* derived in this manner covers the lower slopes (Pl. V, B) and merges into material of alluvial origin without perceptible break. It is obvious that in such places the boundaries of the alluvium must be generalized.

In reconnaissance work like that done in 1916 it is not possible to trace out formation boundaries so accurately that no assumptions need be made. Topographic form, color of rocks as seen from a distance, indications afforded by changes in type of vegetation, and other forms of evidence are considered, but inevitably there will be some error in detail, although the working out of the major relations may prove to be essentially correct.

In the vicinity of Marshall there is an area of metamorphic rocks which extend eastward to the Kuyukutuk and reappear along the Yukon below Russian Mission and still farther east between Mountain Creek and Koserefski River. Greenstones of a rather wide range in composition and origin, probably embracing intrusive rocks as well as flows and tuffs, make up a large proportion of these metamorphic rocks. Closely associated with the greenstones are slates, quartzites, and conglomerates and many intermediate rock types. The greenstones appear to have suffered the most intense changes, but secondary structure has developed in the sediments also. Undeformed acidic dikes cut both the greenstones and the sediments. Although the complete solution of the questions involved in the stratigraphic sequence of these rocks and their mutual relations must await more detailed study, it is now tentatively assumed that the greenstones, including the tuffs and some conglomerates which occur with them, are of late Paleozoic age and that the sedimentary rocks are the metamorphosed equivalents of the Cretaceous beds found elsewhere in this region.

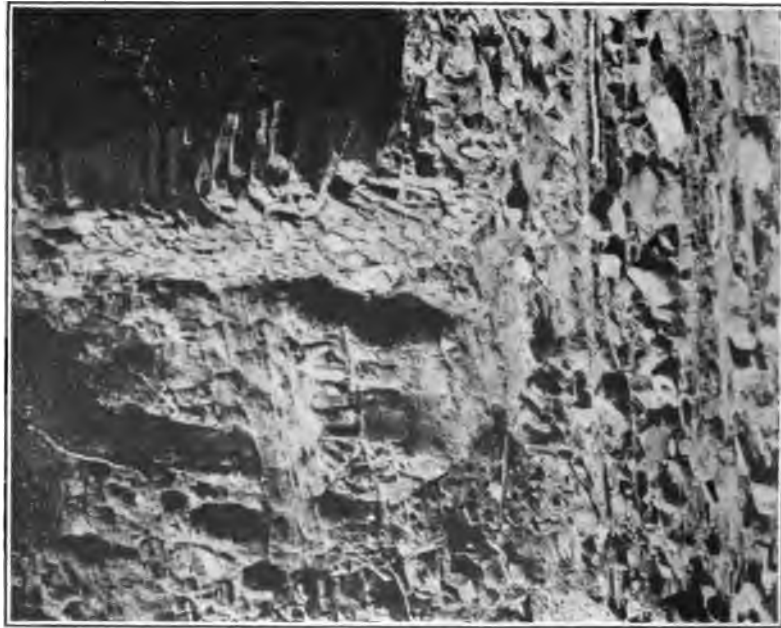
Cretaceous rocks were found on Anvik and Andreafski rivers and probably occupy much of the intervening area. The principal rock types found are conglomerates, sandstones, and shales, which have



A. EROSIONAL EMBAYMENT IN THE BANK OF THE YUKON BELOW HOLY CROSS.



B. ALTIPLANATION TERRACES AND SOLIFLUCTION SLOPES EAST OF FAITH CREEK.



A. BASALT DIKE CUTTING HORIZONTAL BASALT FLOWS,
2½ MILES ABOVE INGRUMIART.



B LOGS IN PEAT IN THE WEST BANK OF THE YUKON,
5 MILES BELOW ANVIK.

locally been metamorphosed into quartzites and slates. Though these rocks are generally thin bedded, with an extreme phase of alternating sandstone and shale layers less than half an inch thick, massive phases also occur in which the individual beds may be several feet in thickness. More or less closely associated with the Cretaceous rocks in the northern and eastern parts of the region are a series of tuffs and flows of intermediate basic types. Some of the flows appear to be intercalated with the Cretaceous sediments. In the southern part of the region are a number of dacitic porphyry dikes of late Cretaceous or post-Cretaceous age. It is probable that some of the intrusions in the vicinity of Marshall took place at the time these dikes were formed.

No sediments of known Tertiary age were found in the area, but at somewhat widely separated points vesicular lavas occur as undeformed horizontal flows (Pl. VI, A), which are either late Tertiary or early Quaternary. Quaternary deposits are found throughout the region. They include the residual mantle of rock and soil on the higher hills and slopes, the gravels, sands, and silts of the terraces and lower hills, and the alluvium that occurs along the stream courses almost to their heads but is most extensive in the lowlands of the Yukon and its larger tributaries.

CARBONIFEROUS GREENSTONES AND ASSOCIATED SEDIMENTS.

AREAL DISTRIBUTION.

Metamorphosed tuffs, flows, and intercalated sedimentary rocks, together with some rocks that may represent altered basic intrusives, occur at a number of places in the Anvik-Andreafski region. In the vicinity of Marshall they form a considerable portion of the bed-rock along the divide between Spruce and Wilson creeks, on the south and west slopes of Pilcher Mountain, and on the south slope of the range of hills to the east of this mountain. This series of rocks also appears at four other localities between the mouth of Koserefski River and Marshall, outcrops being found below Russian Mission, in the vicinity of Bareface Bluff, above Tuckers Slough, and for a short distance along the Yukon at the mouth of Koserefski River.

LITHOLOGY.

A large proportion of these rocks are igneous, but rocks of sedimentary origin make up a minor part of the series. Only in the vicinity of Bareface Bluff are the sediments notably abundant. In the area between Paimiut and Tuckers Slough a few thin beds of conglomerate are intercalated with the flows. The conglomerate

pebbles consist mainly of igneous material, with lesser amounts of chert. Green tuffaceous grits and sandstones also occur at this locality in similar relations to the flows. Small chert grains are fairly numerous in some of the coarser-grained beds. Here and there thin beds of argillitic sand separate the flows. Below Russian Mission occur some grits, the grains of which are almost wholly gray and black chert. In the rocks near Bareface Bluff greenish tuffs and tuffaceous sandstones are associated with red cherts and argillites as well as with greenstone flows.

Near Marshall this series is represented, so far as observed, only by greenstone flows and intrusive rocks, and the associated sedimentary rocks are presumably younger. Several rather widely different types, ranging from schists to massive rocks, are included under the term of greenstones. At the bluff below Marshall the greenstones are extremely schistose, much contorted, and netted with quartz veins, which have also been subjected to deformation. One of the quartz veins noted is 6 inches or more in thickness. At Marshall the deformation appears to have been less intense, although a schistosity which gives the impression of bedding has been developed. Elsewhere on the slopes of Pilcher Mountain and along the ridge east and west from Mount Okumiak the rocks appear gneissoid rather than schistose, with some massive phases in which but little secondary structure has been developed. These various phases appear very different in the hand specimens, but under the microscope nearly all prove to be epidote-amphibole rocks, practically the entire rock being made up of these minerals, with a moderate amount of magnetite and here and there small amounts of quartz or chloritic minerals. Less frequently pyroxene and plagioclase feldspars may be determined.

These rocks are all recrystallized, and there is some doubt as to their original nature, but they probably represent a metamorphosed series of andesite or basalt tuffs and flows which have included some gabbroic intrusives. This conclusion as to the origin of the greenstones is confirmed by their composition at the localities below and above Russian Mission, where they have not been subjected to such intense metamorphic processes and their original nature is more readily determinable. The tuffs and flows are largely basaltic, with augite and labradorite as their principal constituents and magnetite as the chief accessory mineral. Some of the flows are a little more siliceous, the feldspars having the average composition of andesine, and the rock is an andesite. Secondary minerals have been developed to some extent, mainly by the alteration of minerals containing iron, forming hornblende, chlorite, or serpentine. Glass is found in some of the tuffs.

Intrusives in the greenstone series occur at a number of places in the vicinity of Marshall, where they cut the Cretaceous rocks also. (See Pl. IV, in pocket.) Soda granites and quartz diorites make up the larger stocks, and the numerous dikes are dacites. They are discussed under the heading of "Igneous rocks" (pp. 44-47).

STRUCTURE.

The structure in the greenstone areas is rather complex. To some extent it has been induced by the intrusives which have cut the series, but for the most part it is related to broader orogenic features. The intrusion of the soda granite that forms the core of Pilcher Mountain probably produced the complex structure in the area north of Wilson Creek and caused a general doming effect in that area. The structure south of Wilson Creek is open to two interpretations and may have been produced either by close folding or more probably by faulting. The outcrops in this area are massive and afford few structural data. It is notable that the drainage of this area is controlled by bedrock structure. Between Russian Mission and Grand Island the structure can not be determined, mainly on account of the massive nature of the rocks, both the flows and the associated sediments showing no deposition planes. They are, however, much jointed, and along the joint planes considerable movement has taken place.

The sedimentary rocks above and below the mouth of Kako Creek contain prominent joints and are in many places broken by conspicuous faults. Locally the stresses are adjusted by movements along bedding planes, but the effects of such movements are not pronounced. For the most part these rocks have a northeasterly strike and a northwesterly dip, conforming to the regional trends. Both the topography and the rock attitude suggest that they are separated by faults from the sedimentary series in the vicinity of Dogfish Village.

Where their attitude is determinable the greenstones above the entrance to Tuckers Slough strike northeast and dip steeply to the northwest. It appears likely that this dip is reverse, and that the flows represent an overthrust upon the younger sediments. Faulting has been extensive, across as well as along the flow planes and bedding planes of intercalated sediments. The contact with the sediments lying to the southeast and up the Yukon is complicated by faulting, apparently with some intershearing, so that no sharp line between the two series can be drawn. At the mouth of Koserefski River these rocks are massive and the outcrops afford no evidence of their attitude, but, as in other localities, they have been faulted. The general arrangement and distribution of the greenstone areas, flanked

on either side by younger sediments derived from the greenstones, suggests an earlier easterly folding upon which has been superposed a northerly or northeasterly structural trend, which now predominates. Between Marshall and Russian Mission cross faulting has been sufficient to produce great offsets. (See Pl. IV, in pocket.)

AGE AND CORRELATION.

The greenstones and intercalated sediments are the oldest rocks in the region and represent the source of a considerable amount of the material which makes up the Cretaceous beds. No additional evidence from this region as to their position in the geologic column is at hand, and correlations must therefore be made with other near-by regions where more information is available. Maddren¹ describes similar rocks, here correlated with the greenstones, on the north side of the Kuskokwim, 6 miles above Ohagamut, where there is a gradation downward from tuffs through tuffaceous limestones to pure crystalline limestones. Fossils of Artinskian or late Carboniferous age were obtained in the tuffaceous limestones, and it is therefore evident that this period of geologic time was marked by the inception of the volcanic activity which resulted in the formation of the greenstone series.

CRETACEOUS SEDIMENTS.

AREAL DISTRIBUTION.

Sediments of Cretaceous age are widely distributed throughout the lower Yukon Valley. In the Anvik-Andreafski region they appear about the margins of areas of uplifted older rocks and doubtless occupy much more territory than is indicated on the geologic map (Pl. III, in pocket). They probably underlie considerable portions of the drainage basins of Anvik, Hawk, Chvilnuk, and Andreafski rivers and possibly that of the Golsova also. The rocks on the headwaters of Bonasila River are probably Cretaceous, and the sediments associated with the flows and tuffs on the Stuyahok are believed to be of the same age. Tuffs and flows which may be late Upper Cretaceous or early Tertiary occupy considerable areas in the Anvik, Bonasila, and Stuyahok basins and appear also along the Yukon, forming the hills along its west bank immediately below Anvik and below the mouth of the Bonasila.

The sedimentary rocks associated with the greenstones near Marshall have been considerably metamorphosed but, aside from the secondary metamorphic features developed in them, are not essentially

¹ Maddren, A. G., The mineral resources of the middle Kuskokwim region, Alaska: U. S. Geol. Survey Bull. — (in preparation).

different from the Cretaceous beds, of which they are believed to be the metamorphosed equivalents, and with which they are mapped. (See Pls. III and IV, in pocket.)

LITHOLOGY AND STRATIGRAPHY.

The sediments of this period exhibit a great diversity in lithology. Conglomerates and fine-grained argillites represent the extremes in texture, but sandstone and argillites are the most common rock types. Grits are fairly common in some parts of the area, and in places are of considerable thickness.

Some of the conglomerate appears to be basal and made up of pebbles of the older metamorphic rocks, greenstones, and chert predominating. Quartz pebbles and cobbles are found in these conglomerates but only in small amount. Here and there are intraformational conglomerates a few inches in thickness in which rounded white quartz pebbles form almost all the larger rock fragments. On account of the light color of the material forming these beds, debris from them is much more conspicuous than that from other rocks, and they appear to be more widely distributed than is indicated by the number and width of the conglomerate beds seen in outcrops.

In the basal portion of the Cretaceous sediments sandstones appear to constitute the dominant lithologic type. There is, however, every gradation between the conglomerates and the sandstones, both in size and in character of grain, and locally the grits attain considerable prominence. The individual grains of the grits are fragments of greenstone, chert, or other rocks, as well as quartz and feldspar in greater or less amount. Feldspar is found in varying amounts in almost all the sandstones. In some rock phases the feldspar grains appear to be as numerous as those of quartz. The ferromagnesian minerals appear in a few places, but they are as a rule largely, if not completely, altered to secondary minerals. Small grains of chert or slate are discernible in thin sections of some of the sandstones. Calcite is apparent in most sections in amounts ranging from a few small grains, which may represent replacement near fissures, to fairly large areas in which some of the calcite was probably deposited as grains with other rock constituents, although much of it may represent later replacement or deposition from solution.

The finer-grained rocks comprise both siliceous and argillaceous types, as well as gradational phases between the two. Some of the siliceous rocks are so fine grained and so badly altered that only a small proportion of the grains, mostly quartz with some plagioclase feldspars, can be readily determined. The argillaceous beds show several phases, of which some are due to differences of induration

and some to differences in composition. The least indurated beds were called mudstone in the field. They range in thickness from a few inches to several feet, and one of their most common characteristics is the occurrence of numerous ellipsoidal nodules, from some of which successive layers may be removed. These nodules are presumably of concretionary origin, although possibly due to processes of weathering. The more strongly indurated argillites have closely spaced cleavage planes and break up into angular faceted blocks, in places forming the so-called pencil slates. True slates, which break up into thin plates with parallel surfaces, are only occasionally found.

It is not possible to make an approximation of the thickness of the Cretaceous rocks within this region, as no continuous section from the base to the top of the series is exposed. Faulting, largely of the normal type, is common, and there is probably much repetition of beds in outcrops on this account. Nevertheless there are several localities in which the section exposed is from 300 to 700 feet thick, and lithologic differences in these sections are sufficiently great to warrant the belief that they represent different portions of the series. If this belief is correct, the minimum thickness for the Cretaceous is at least 2,000 or 3,000 feet, and the maximum may be 10,000 feet or more.

LOCAL FEATURES.

ANVIK RIVER.

Mudstones or consolidated shales are the most characteristic deposits along Anvik River. Some of these shales display in a very pronounced manner the ellipsoidal nodules already mentioned. The rocks are characteristically gray to very dark gray, and in many places they have a greenish tinge. On weathered surfaces red, yellow, and brown tones are pronounced. Fine-grained siliceous rocks, locally cherty, occur with the mudstones.

The sandstones are not so massive as those farther south, 6 to 8 inch beds between shaly layers being the most common, although sandstones 5 feet or more in thickness are occasionally found. These are almost universally gray with a greenish tinge, which may be lacking, however, on some leached beds that appear cream-colored on the surface.

Thin sections examined show a considerable amount of plagioclase feldspars, of which albite is the least altered. In many sections the more basic feldspars are not readily recognizable on account of the amount of decomposition they have undergone. Many of the beds are calcareous. In some a large amount of the matrix is calcite, and apparently some of the basic plagioclase feldspars also have been replaced by calcite, of which the lime radicle has been chiefly derived from the decomposition of the feldspars.

KOSEREFSKI RIVER TO MOUNTAIN CREEK.

Above Holy Cross, and on the west and north bank of the Yukon opposite Paimiut, coarse-grained clastic rocks predominate. Conglomerates, grits, and sandstones alternate locally in beds 100 feet or more in thickness or in massive beds whose attitude and thickness are not determinable from the outcrops. Argillites of considerable thickness are present here and there, but more commonly the argillite occurs as thin beds or partings in the other rocks, especially near Paimiut. Most of the pebbles in the conglomerate consist of green, black, or gray chert, but pebbles of gabbroic or basaltic rocks are rather common. The grits are essentially the same in composition as the conglomerates, representing a greater comminution of material from the same source. Similar material is found in the sandstone, of which quartz, feldspar, and chert grains are the principal constituents. All these coarser-textured rocks show on exposed surfaces a predominance of rounded forms, which have probably been produced by exfoliation. The rocks are all indurated, and some of the more quartzose sandstones might better be termed quartzites and others graywackes.

The argillitic rocks are gray to nearly black indurated shales, some of which contain small amounts of carbonized material. The argillites contain many closely spaced partings at various angles, so that the débris resulting from their breaking down is mainly in angular fragments. Some of the rock that breaks down into elongated fragments is called pencil slate. True slates are not common in this area.

DOGFISH VILLAGE.

Fine-grained rocks predominate along the Yukon from the mouth of Mountain Creek to a point below Dogfish Village. They are largely siliceous and include cherts and quartzites as well as some fine-grained quartzites containing a considerable amount of argillaceous or possibly tuffaceous material. Associated with the finer-grained rocks are a few beds of grits and conglomerates, but the pebbles of the conglomerates are mostly not over an inch in diameter. A large proportion of the pebbles are of green and horn-colored chert.

In the range of hills north of Dogfish Village a great many dacite porphyry dikes intrude the sedimentary rocks. These dikes have probably increased the induration in the siliceous beds, rendering them more resistant to erosion than rocks in adjacent areas, so that the highest peaks in the region are found within these rocks at a comparatively short distance from the river.

DEVILS ELBOW.

A rather wide lithologic range appears in the outcrops along the north bank of the Yukon between Grand Island and Round Point. Sandstones and argillite, comparable to those of the Cretaceous areas above discussed, are included in the series, which contains, in addition, however, many fine-grained siliceous and argillaceous sediments of somewhat different character. These sediments are thin bedded for the most part, and in places show numerous alterations of the two principal phases. Some of these beds are light colored, in places nearly white on the weathered surfaces; other beds are green or brown or darker gray. Where these differently colored beds occur together, as opposite the island about 2 miles below Toklik, the appearance of ribbon banding is pronounced. It is probable that some of the green bands may represent altered ash beds or tuffs. The sequence of the beds is not wholly clear, but there seem to be fairly good structural grounds for considering these rocks younger than the sandstones and argillites.

It was noted in this small area of Cretaceous rocks more conspicuously than elsewhere that the exposed sections of small ridges that are truncated by the river commonly show the effects of weathering on both the upstream and downstream sides near their bases. This weathering is made conspicuous by the rusty red color of the residual material formed by the decomposition of the hard rocks. Decomposition has progressed so far that it is not always possible to determine the contact of the rocks with the overlying silts where the entire section is exposed. In the centers of the truncated sections the rocks are weathered comparatively little, erosion proceeding so rapidly that it almost keeps pace with weathering.

MARSHALL.

In the area where mining operations are being carried on near Marshall greenstones of various types predominate, but there are some sedimentary rocks that are considered Cretaceous. Their distribution is shown approximately on the geologic map (Pl. III, in pocket). In this area sandstones and argillites have been altered to quartzite and slates, and conglomerates carrying quartz pebbles have been subjected to pressures so great that the pebbles have been sheared and distorted. Cherts are interbedded with the other sediments, both light and dark gray varieties being seen either in outcrop or in the gravels on Disappointment Creek.

The sediments are cut by a number of dikes and larger intrusive bodies of acidic rock, which are discussed under the heading "Igneous rocks" (pp. 44-47.)

CHVILNUK AND ANDREAFSKI RIVER BASINS.

In the basins of the lower Kuyukutuk, Chvilnuk, and Andraefski rivers the carving of the stream valleys has been greatly facilitated by the occurrence of an easily eroded bedrock. Both the Kuyukutuk and the Chvilnuk flow into a slough of the Yukon after passing for a considerable distance through the Yukon flood plain. Similarly, Andraefski River and its east fork flow in rather wide valleys and join after reaching the flood plain of the Yukon. It is probable that the wide valleys of these streams are also due partly to the fact that they were formed when the base level of erosion was much lower than it is now.

Along the route traversed the Cretaceous rocks appear for nearly 2 miles below the mouth of the Chvilnuk, and are succeeded on both sides of the river by Quaternary river-laid sands and flood-plain deposits, which extend to the mouth of Andraefski River. Here the Cretaceous beds reappear and extend up the main Andraefski as far as the traverse was carried, and it is known that they form the hills along the north bank of the Yukon for several miles below the mouth of the Andraefski.

The rocks near Pilot station are slightly different in some phases from those seen elsewhere. Some of the beds show striking alternations of sandstone and argillite laminae. Lenticular sandstone layers appear in the argillites. The argillitic material is usually so nearly black that in the talus it resembles "bloom" from a coal seam. Some of the sandstones are highly calcareous.

Movement along bedding planes has been common in this area, and in certain localities slickensides appear on practically all the bedding surfaces. In the black argillites graphite and sericite occur along the slickensides.

Along the Andraefski conglomeratic phases are more common than near Pilot station. They appear generally in sandstones several feet thick, and the pebbles have a maximum diameter of about 2 inches. Some of the pebbles are white vein quartz, but more of them consist of argillitic material. The argillite pebbles have a poor cleavage, which has been developed since the formation of the conglomerates.

The argillitic rocks are mainly slaty, but they include some fossil leaf-bearing beds that have suffered comparatively little metamorphism, being scarcely more indurated than well-compacted shales. Closely spaced joint cracks, however, cause the rock to break up into angular fragments and make it difficult to obtain determinable leaf imprints. In the sandstones the leaves are represented only by a very faint smear of graphite and the stems by indeterminable compressed carbonized rods. Besides the leaves, some of the argillitic beds also contain distorted casts of invertebrates, and in a few places the two

fossil types occur together. This association, together with the alternation of rock types and the presence of well-preserved fossil ripple marks, is indicative of near-shore or shallow-water deposition.

STRUCTURE.

Massive bedding is the general rule for the sandstones, grits, and conglomerates and is found in some of the argillitic rocks as well. In some of the coarser rocks the bedding planes are not determinable, but in the finer-grained clastic rocks slight textural or color differences make them apparent. In places a thin band of argillite appears between heavy beds of sandstone or grit.

In consequence of the deformation to which the entire series has been subjected, jointing is practically universal, but naturally the joint planes are more closely spaced in the argillites than in the sandstones and grits, so that talus from the argillites is composed of small angular, faceted pebbles, whereas that from the sandstones and grits is made up of large boulders. Locally metamorphism has been so intense as to convert the argillites to slates that have a typical platy cleavage, mostly parallel to the bedding.

The sandstones show in many places a slight tendency to assume rounded forms, between joint cracks, which is attributed to exfoliation through weathering. In the argillites a somewhat similar feature may be due in part to weathering, but the exceptionally well-developed ellipsoids sometimes formed are probably concretionary.

Deformation has been most severe in the vicinity of Marshall, but exposures there are not sufficient to indicate the attitude of the beds. Elsewhere sections along the Yukon and its larger tributaries afford opportunity for studies of the structure. The dips for the most part are less than 45° , but on the Anvik and on the Yukon below Toklik beds standing vertical or having reverse dips were seen. The beds strike mainly in a northerly or northeasterly direction, but near the Devils Elbow some northwesterly strikes were measured. The older greenstones are in general flanked on both sides by Cretaceous sediments dipping away from the greenstones or by possibly Cretaceous tuffs and flows, a distribution of outcrops that suggests an anticline whose crest has been truncated by erosion. Accompanying minor open folds are seen in outcrops between Akahamut and Ohogamut. In the group of hills north of Dogfish village there are cross folds in which the nearly vertical beds strike almost at right angles to the river and to the general trend of the formations. Near Marshall either close folding or faulting is indicated by the distribution of lithologic units and the arrangement of drainage lines. It is probable that both folding and faulting have taken place, for the rocks in the few exposures at Marshall and at the bluff below appear much faulted and exhibit crumpled and crenulated surfaces.

In no part of the region do the Cretaceous rocks appear undeformed, but except as noted above the stresses have been relieved by the formation of open folds and by faulting, mostly of the normal type. In nearly all outcrops faults along planes nearly perpendicular to the bedding were observed, and although many of these are of comparatively small throw, the occurrence of others having throws ranging from several feet to possibly several hundred feet and of numerous faults along bedding planes, which are not so readily apparent, is indicative of the magnitude of the stresses to which the region has been subjected.

AGE AND CORRELATION.

Fossil plants were collected at several localities within the Anvik-Andreafski region, on Anvik River, on the Yukon between Holy Cross and Paimiut, and on the Andreafski about 11 miles above its mouth. Invertebrate fossils were found in the same bed as plant fragments on Andreafski River about half a mile above its mouth and were also obtained near the fossil-plant locality farther upstream. The fossil plants were examined by F. H. Knowlton. Those from the Anvik and Yukon river localities are indeterminable. Concerning the collection from the east bank of Andreafski River 9.2 miles northeast of Andreafski he reports as follows:

7250. Fragments of bark and wood. Also fragments of dicotyledons of two kinds, with little or no margins preserved. I also note *Podozamites lanceolatus* and *Taxodium* sp. I am free to confess that I am not able to place this lot satisfactorily, though there would seem to be no doubt of its being Cretaceous. If it depended on the *Podozamites* I should incline to put it well down in the Cretaceous, but the dicotyledons indicate that it can hardly be older than middle Cretaceous.

Determinations of the invertebrate fossils were made by J. B. Reeside, jr., as follows:

9774. 16 A Ha 134. East bank of Andreafski River 9 miles northeast of Andreafski:

Small unios of three or four probably undescribed species.

Fragment of gastropod.

9775. 16 A Ha 135. East bank of Andreafski River 9.2 miles northeast of Andreafski:

Sphaerium sp.?

Unio sp., small forms like those in lot 9774.

Goniobasis sp., fragments of a sharp-keeled form and of a multilined form.

Viviparus sp., fragments of a high-spired form and of a stout low-spired form.

9776. 16 A Ha 140. West bank of Andreafski River 1.5 miles below Andreafski:

Ostrea sp., small unsculptured form.

Fragment, apparently of a large pelecypod with a sculpture like that of some species of *Inoceramus*.

Collections 9774 and 9775 contain the same fauna of fresh-water pelecypods and gastropods. The unios do not differ essentially from forms collected by Collier, Atwood, and Hollick along the Yukon at and below Nulato. All are probably undescribed. The same is true of the gastropods, specimens collected by Collier, showing no appreciable differences. The fauna is supposed, on physical grounds, to be Cretaceous, though in itself it does not afford conclusive evidence of its age, for the types represented are of long range.

Collection 9776 contains a form of *Ostrea* inseparable from material collected by Hollick near Nulato and represents a brackish-water fauna. No such forms are known in the Tertiary of the entire region, and this lot also is probably Cretaceous, though the fossils alone are not sufficient proof.

Other collections made in 1902 by A. J. Collier, in 1903 by Arthur Hollick, and in 1907 by W. W. Atwood and H. M. Eakin include specimens obtained along the Yukon from a point near the mouth of Melozitna River to a point about 10 miles above Anvik and probably represent the same series of rocks as those found in the Anvik-Andreafski region. The plants from these collections were studied by Hollick, who summarizes them as follows:

There is a complex mixture of floras, not only from locality to locality, but also in many of the individual collections. Localities of lower or middle Cretaceous strata alternate with localities where the beds are of Upper Cretaceous or possibly of Tertiary age, some of them only a few miles distant from each other, and some of the collections contain floral elements so diverse that it is impossible at present to correlate them satisfactorily with any known or described flora. There can be no doubt that the collections in at least two of the localities indicate strata as old as lower-middle Cretaceous; the others indicate strata which are either Cretaceous or questionably as young as basal Eocene.

Marine and fresh-water invertebrates from the same region have been determined by Stanton to be mainly of Upper Cretaceous age. The wide distribution in near-by regions of known Cretaceous rocks that are lithologically similar to those in this region, together with the corroborative evidence of the fossils found, even though they were obtained at rather widely separated localities, and only those collected on Andreafski River are of stratigraphic value, affords grounds for the belief that the consolidated sedimentary series as a whole is of Cretaceous age. So far as has been determined, however, the entire Cretaceous section may be present, together with basal Tertiary deposits. It is not impossible that Triassic or Jurassic rocks occur in the areas mapped as Cretaceous, but no evidence of such age for any of the rocks was found.

Some of the effusive rocks on Anvik River appear as intercalated flows, presumably near the top of the series, and are therefore late Upper Cretaceous or early Tertiary. These flows are believed to belong to essentially the same period of igneous activity as the extravasation of the flows, the deposition of the tuffs in the Bonasila basin, and possibly the intrusion of the earlier Cretaceous sediments by dikes of acidic rocks.

Cretaceous rocks are widely distributed elsewhere in western Alaska, and probably have a greater areal extent than all other consolidated deposits in this general region. From the Kobuk southeastward to the Melozitna and southward to Nulato and Norton Sound, as well as along the west bank of the Yukon still farther south, both Lower and Upper Cretaceous rocks are found. South of the Yukon they crop out in an area extending from the headwaters of the Nowitna and its tributaries to and far south of the Kuskokwim, including the Innoko and Iditarod districts. South of the Kuskokwim volcanic rocks appear in the series. Cretaceous strata occupy considerable areas on the Alaska Peninsula, where sedimentation was apparently uninterrupted during the transition period from Upper Cretaceous to early Tertiary time. Evidence of the wide distribution of the Cretaceous rocks elsewhere in Alaska is afforded by their presence along the north front of the Endicott Range, in the Yukon-Tanana region, in the Chitina Valley, and in southeastern Alaska. Close correlation of the Cretaceous of the Anvik-Andreafski region with that of other regions should not yet be attempted. It is, however, safe to make broad correlations and to state that the deposits of the entire lower Yukon Valley were laid down in the same or adjacent basins during Cretaceous and Eocene time. A concept of the conditions of sedimentation in great embayments, with alternations of periods of quiescence, subsidence, and occasional elevation of the land surface, affords a means of understanding how such a series of rocks might have been formed.

TERTIARY SEDIMENTS.

As suggested above, a portion of the sediments mapped as Cretaceous may be early Tertiary. If this is true, however, the Cretaceous and Tertiary localities can be separated only through the finding of determinative fossils, as the rocks of the two systems, if both are represented, are lithologically similar.

It is likewise possible that the series of tuffs and flows intercalated with the sediments at one locality on Anvik River may be Tertiary. Together with the intrusives below Holy Cross, these rocks are considered in the foregoing description of the Cretaceous rocks, for they are of the same age as rocks supposed to be Cretaceous. The effusive and intrusive rocks are considered as belonging to the same period of igneous activity, although no direct evidence to support this inference was seen. No sediments known to be of Tertiary age were found. It is likely that during Tertiary time, especially during the later part, the present topography was outlined, although the base level was considerably lower than at present and the relief was greater. Only terrestrial deposits were formed, and these have been

almost, if not entirely, removed by Quaternary erosion or covered with the products of erosion.

At two localities sediments occur which may be of Tertiary age. Near the mouth of the small creek entering Andreafski River about 200 yards below the post office at Andreafski is a very small exposure of blue clay which differs from any Quaternary deposits seen. On the Yukon $2\frac{1}{2}$ miles above Ingrumhart gravel beds are overlain by basaltic flows, but as the pebbles of the gravel are similar in composition to the overlying flows, the presumption is that they belong to the same period as the lavas. No direct evidence is at hand as to the possible Tertiary age of either the clay or the gravels. No fossils were found in either place, and the relations of these beds to other rocks are such that they might be either Tertiary or Quaternary. They are described in connection with the Quaternary deposits.

QUATERNARY SEDIMENTS.

AGENCIES AND PROCESSES.

The unconsolidated deposits found in this region are of many types and owe their presence to different agencies and processes. Silts and gravels that lie at elevations well above the present stream courses undoubtedly were laid down in part as deltas in embayments at a time when much of the region was inundated. On reelevation of the land surface drainage lines were again established. It appears likely that for the most part the courses of present streams are those of the period following the reelevation. These streams have laid down alluvial deposits of gravel, sand, and silt, the extent of which is generally limited by the flood plains, so that along the smaller streams the deposits are but a few feet in width, whereas along the Yukon and its larger tributaries they extend for many miles.

On the higher hills and ridges the products of comminution by mechanical and chemical forces form a mantle over much of the surface, either as soil, as talus, or as broken residual rock débris. So completely do these deposits conceal the underlying rock that the nature of contacts and the attitude of individual beds are obscured.

Vegetation serves to hide still further the nature of the material upon which it grows, especially on all but the steepest slopes in the untimbered areas, where lichens, mosses, and grasses make up a protective mat and in some places form peat beds that may be several inches thick.

Practically the entire region is thus mantled with Quaternary deposits which mask what lies beneath. Bedrock is as a rule seen only along the streams and at or near the crests of hills or ridges.

Many of the outcrops on hills or ridges cover only small areas and are so much affected by creep or jointed by frost as to be of little service in the interpretation of structure.

The Quaternary deposits as mapped include only the older silts and recent alluvium, not the residual mantle of soil, talus, and rock débris or the covering of peat, which are not mapped. Although the older silts and recent alluvium are described separately, they are mapped together, as sufficient data were not obtained to map them individually. There is not everywhere a topographic break between the older and younger sediments, and contacts that are not exposed in cuts along the banks of streams are masked by vegetation.

Between the higher-lying residual soil or talus on slopes and the silts or alluvium there is generally no sharp line of demarcation and apparently every stage of gradation in topographic form exists. As a consequence the boundary lines as drawn between the areas of water-laid deposits and of bedrock are of necessity approximations.

OLDER SILTS AND GRAVELS.

In the valleys of Bonasila and Anvik rivers and at numerous places on the Yukon and one locality on the Andreafski are silt and gravel beds which lie at considerable elevations above the present stream courses. These deposits were noted in sections along streams almost 300 feet above sea level. The exposure usually has the appearance of a dissected terrace, sloping back from the top of the section at a very low angle. Above such terraces and farther back from the drainage courses rise still other terraces to elevations of about 600 feet, in which no sections were seen. It is significant, however, that rocks crop out but rarely below 600 feet, except along stream cuts, and that outcrops are considerably more common above this elevation. Sections of the older gravels and silts are not especially common, even along streams, but exposures were seen in many parts of the area and afford evidence of the widespread distribution of such sediments.

At Anvik silts cover the underlying bedrock, which is exposed only along the river beach. Two miles up Anvik River sand and silt make up the bluff that rises steeply about 100 feet above the river. Farther upstream they appear to merge with the present flood-plain deposits of the Anvik. About 4 or 5 miles below the mouth of the Beaver a small stream enters the Anvik from the east. For a quarter or half a mile above its mouth the silts form a bluff 20 to 30 feet high, into which the river is cutting. At the upper end of the bluff bedrock is exposed in a much weathered outcrop, which is overlain by weathered gravels, and these grade within a short distance into the conformably overlying silts. On the Stuyahok a bluff was noted in which the

gravels occurring at the upper end grade downstream into finer material. At the upper end of the outcrop practically the entire section consists of gravel; a few hundred feet downstream gravels and sands are interbedded; still farther downstream practically the entire section is fine sand or silt. On the lower Bonasila the river cuts against the low hills between Bonasila and Anvik rivers, giving exposures of 30 feet or more of fine sands and silts. On the Anvik side, hills of similar material rise sharply 150 feet or more directly from sloughs of the Anvik.

Between Anvik and Russian Mission the older unconsolidated deposits are seen in few exposures, but well-developed terraces such as are associated with these deposits elsewhere appear at several levels. Of these terraces the one at 600 feet seems to be the most persistent. Along the hill facing the river erosion has removed not only the unconsolidated sediments but considerable of the underlying bedrock, and it is only in the small lateral valleys that the sediments remain and appear as terraces. Much the same conditions are found below Russian Mission, but the exposures are somewhat better. In the small slough about 2 miles below Russian Mission at least 200 feet of silts are exposed in what appears to be an old bedrock depression. On either side of this exposure silts to a depth of several feet overlie the bedrock, as if the old depression has been filled to the level of its banks, and sedimentation had then continued over both the filled depression and the adjacent low hills.

At several places farther down the river essentially similar features may be seen, the gravels and silts that fill the lateral tributary valleys still persisting. Such deposits are especially noticeable 2 miles below Toklik, where 15 to 20 feet of silt and fine sand appear above 50-foot exposures of the Cretaceous rocks. From the upper edge of the silt exposure to the crests of the flat-topped hills 150 to 200 feet above the river the slopes are less steep and are covered with vegetation. It seems likely that these hills represent silt terraces on the fronts of the hills farther back from the river. Similar terraces are seen near the Cross Slough but are less distinct elsewhere, as at Marshall, on account of the much gentler slope of the bedrock.

On Andreafski River terraces are only faintly indicated. The dark-gray or blue-gray mud and clay banks of the stream are in places 15 to 20 feet high and possibly represent the products of flood-plain deposition, though they may be older. The gravels seen at the end of the Survey traverse, 8 or 10 feet thick where exposed, may also be river borne or they may be the basal beds of the older gravels, sands, and silts, but no sections were observed here or elsewhere on the Andreafski of a nature to confirm the suggestion as to this occurrence which the terrace forms present.

Near the mouth of the small stream below the warehouses of the Northern Commercial Co. at Andraefski is a small outcrop of light blue-gray clay. Its age and origin are wholly in doubt. It may represent a remnant of late Tertiary sediments but appears more likely to be Quaternary and equivalent to the older gravels and silts or to more recent river-laid sediments.

The exposure of gravels under the flows above Ingrumhart is discussed in connection with the Quaternary igneous rocks. (See p. 49.)

The most satisfactory explanation of the origin of these high-lying unconsolidated sediments is afforded by the hypothesis that an inundation of the region covered points now 600 feet or more above sea level and that the gravel, sand, and silt represent the deposits laid down by the advancing sea and reworked by the retreating sea during the period of emergence. From the occurrence of deeply buried valleys such as those on the lower courses of Anvik, Bonasila, Koserefski, Kuyukutuk, and Chvilnuk rivers and some of the smaller streams it is evident that at the beginning of the period of inundation the base-level of erosion was lower and the land stood considerably higher above the sea than at the present time. The record of the inundation and filling in of depressions below the present land surface is concealed by the sediments laid down at that time and by the later alluvial deposits. If elevation and subsidence took place fairly uniformly over the entire region, as is indicated by the presence of terraces at the same elevation at widely separated localities, the outlines of the sea at successive stages may be closely approximated from the topographic map (Pl. I, in pocket). From Russian Mission to the Kuskokwim as well as west to Bering Sea the deltas of the Kuskokwim and Yukon were inundated, and embayments reached far up these streams and their tributaries. At successive stages of the inundation deltas were formed in the embayments at the mouths of the streams, and the delta deposits are now represented by gravel beds such as those on the Stuyahok or on the Anvik above the mouth of Yellow River. Beach deposits were formed along shore lines at about the same levels, and these may be represented by the gravels near Anvik. Fine sands and silts were laid down in the deeper water of the embayments. Deposits of this type form the plain through which the lower Stuyahok, Bonasila, and Anvik rivers now flow. The fine and unconsolidated nature of the material facilitated the rapid cutting of the stream courses in adjustment to new grades, and later erosion by lateral cutting has produced wide valleys and flood plains intrenched in these older sediments. None of the other large streams were traversed by the Survey party, but it seems likely from the evidence afforded by the low terraces along the Yukon as far down as Marshall that inun-

dation occurred there under the same conditions as elsewhere, and that similar deposits will be found in the valleys of Kuyukutuk and Chvilnuk rivers.

No direct evidence was found in the region as to the age of these deposits, except that there is generally no sharp line of demarcation between them and the products now being formed by residual decomposition, solifluction, alluviation, and other processes.

Silts and gravels essentially similar in character to those in the Anvik-Andreafski region are said to be widespread throughout the lower Yukon and Koyukuk valleys.¹ The best exposures of these deposits along the Yukon are in the Palisades below Tanana and the high silt bluffs about 8 miles below Loudon telegraph station. No such sections have been noted in the Innoko and Iditarod valleys, although Maddren² mentions silt banks 80 feet high on the lower Innoko, but the occurrence of 50 to 70 feet of muck above 5 to 20 feet of gravel on Poorman and Flat creeks, in the Ruby district,³ and of 70 feet of muck above 30 feet of gravel on Boob Creek, in the Innoko district, indicates that processes other than alluviation were active in those areas. These deposits and those on the Yukon are attributed by the writer to inundation, the agency that caused the formation of the silt and gravel beds in the Anvik-Andreafski region.

The fresh-water Pleistocene invertebrate fossils found in the silt at the Palisades are presumed to have lived in a fresh-water estuary at an early stage of the inundation. In the silts above Anvik Gilmore⁴ collected remains of Pleistocene mammals, finding bones of mammoth and bison about 5 miles above Hall Rapids, and W. C. Chase, of Anvik, found the lower jaw of *Elephas* near Grayling. Gilmore also mentions a reported Pleistocene fossil locality on the Yukon-Kuskokwim portage. Other such localities in the vicinity of a lake south of Andreafski and a lake near Fort Hamilton were reported to the writer. A large bone fragment seen at Andreafski was said to have come from the locality near old Fort Hamilton. The Pleistocene mammal bones found by Gilmore near Hall Rapids were similar to others⁵ found by him at the Palisades, on the Nowitna, and at other places in the Yukon basin. Similar fossils were seen by the writer

¹ Eakin, H. M., The Yukon-Koyukuk region, Alaska: U. S. Geol. Survey Bull. 631, pp. 53-63, 1916; The Cosna-Nowitna region: U. S. Geol. Survey Bull. 667, pp. 35-36, 1918. Mertie, J. B., and Harrington, G. L., The Ruby-Kuskokwim region, Alaska: U. S. Geol. Survey Bull. — (in preparation). Gilmore, C. W., Smithsonian Misc. Coll., vol. 51, No. 1807, 1908.

² Maddren, A. G., The Innoko gold placer district, Alaska: U. S. Geol. Survey Bull. 410, p. 58, 1910.

³ Mertie, J. B., and Harrington, G. L., The Ruby-Kuskokwim region, Alaska: U. S. Geol. Survey Bull. — (in preparation).

⁴ Gilmore, C. W., op. cit., p. 12.

⁵ Gilmore, C. W., op. cit.

on many of the creeks in the Ruby district. This fauna serves to correlate the silt in the localities where evidence of it is found and to furnish evidence of its Pleistocene age.

Shell fragments were also reported as having been found in test pits during the course of prospecting on the flats near Willow Creek. These were not seen by the writer, but from the description given they appear to have been marine.

MODERN STREAM DEPOSITS.

Throughout the region the streams are transporting and laying down gravels, sands, and silts, representing reworked older material of similar texture, either of alluvial or marine origin, as well as soil and other comminuted products of chemical and mechanical disintegration. In all the streams except the Yukon the water is clear, except as it is discolored by vegetable matter or, during flood stages, by silt and sands. It appears likely that part of the deeper-lying gravels found in prospecting on some of the streams were formed at an earlier time and possibly by other agencies, but further study will be required to determine these points. The creek gravels along some of the streams near Marshall are discussed under "Mineral resources" (pp. 59-63).

In the lower reaches of the rivers tributary to the Yukon gradients are low and stream velocities appear to be controlled largely by the stage of water in the master stream. This feature is well displayed by Bonasila River. On July 6, 1916, the current in this stream was barely perceptible even at 20 miles above the Yukon; two weeks later, when the Yukon had fallen 6 feet or more, the current in the Bonasila was noticeable almost to its mouth. During stages of high water the silt-laden Yukon overflows its own lowlands and those of many of its tributaries and deposits most of the fine sands and silts. As a result the banks of the lower reaches of these streams are made up wholly of silt, largely deposited by the Yukon. Farther up the tributaries the silts are the result of flood-plain deposition by the streams themselves, and although the banks may be 6 to 12 feet high, they usually contain sand and gravel layers near the base, and gravel bars are normally found at bends in the streams. Oxbow sloughs and lakes, resulting from the cutting through of meander loops, are of common occurrence in the flood plains. Nearer their heads the stream gradients increase, the flood plains become narrower, and the alluvial deposits include more and more gravels and sand.

The sediments laid down by the Yukon are more striking than those of the smaller streams. Stages of water 30 or 40 feet above

the normal are reported, and for many miles along the river the banks are not over 20 feet high. On the left bank flood-plain deposition reaches back several miles from the river, but on the right bank the river cuts bedrock at many places, so that flood-plain deposits on this side are usually of small extent. The rate of deposition by the Yukon was very well shown in a cut bank at the edge of a marsh near the mouth of the Bonasila. In this bank thin bands of vegetal material alternate with beds of fine sand and silt from a quarter of an inch to 3 inches in thickness. In a section of 3 feet about 50 such silt beds appear; and as each layer of vegetal material probably represents the growth of one season, or possibly two, and each layer of sediments represents the deposition during the period of overflow, mainly in the spring, it seems reasonable to presume that the time required for the accumulation was approximately 50 years, or 250 years for the accumulation of the sediments represented in the 15 feet exposed in the cut bank. Conditions appear to have been exceptionally favorable for sedimentation and preservation from erosion at this place, and it does not follow that sedimentation is proceeding at this rate everywhere in the region. At several places, however, the steamboat channels have changed considerably in the last 15 or 20 years, the old channels having filled up so as to be impassable to the larger boats, and sloughs have been cut through to form new channels. Thus Poltes Slough at Marshall is now used by the steamboats and is rapidly cutting a larger channel, while the much larger old channel is being so rapidly filled that none of the steamers now follow it. Above Paimiut the main stream formerly flowed to the north of Horse Island, but it now flows south of the island, and the old channel is filling. At the Devils Elbow similar filling has taken place; the middle slough, formerly used by steamers, is no longer passable, and the large loop of the elbow is the principal channel, although some of the largest boats pass through Cross Slough.

The sediments of the Yukon are mainly fine sands and silts, and little gravel is to be found except at the mouths of small streams entering the river from the right. Ice-rafted pebbles from these gravels may be seen here and there on bars or on the left bank of the river. Below Dogfish village some of the streams have built gravel deltas out into the Yukon. The sediments that were laid down from waters flowing with considerable velocity consist mainly of sand, as in the numerous bars covered at high water and the flood-plain sands near the banks of the streams. Quartz and feldspar grains are the principal minerals, but a few deposits contain some mica. The sand was tested wherever the banks were sufficiently dry and was found to contain some magnetite. Below Russian Mission a considerable

amount of magnetite was seen in the sand, and this is thought to have caused the local magnetic disturbance that affected the needle of the alidade compass.

The finer silty material is laid down in slack water and forms most of the deposits in depressions away from the river, or in the shallow dead water found in places along one bank, as on the south side below Paimiut, where mud 2 or 3 feet deep forms the wide beach between the steep banks cut at high water and the water's edge at normal and low stages.

ORGANIC DEPOSITS.

On all but the steepest slopes in this region the underlying rock or soil is covered by vegetation, for the most part moss or lichens, although in some places grasses and other plants predominate. At high elevations, where there is usually fair drainage, vegetal accumulations are slight in amount. On gentle slopes or on the crests of rounded ridges mosses and lichens, together with leaves and grasses, form a practically continuous mantle, which is, however, generally not more than a foot in thickness over any extensive area. On flat-topped hills, under favorable conditions, these accumulations may reach slightly greater thicknesses. The most extensive deposits, however, are formed along the poorly drained areas within or slightly above flood plains. In such situations the conditions for growth seem to be most favorable and accumulations of peaty material are common. For the most part these deposits are formed from the same plants as those at higher elevations, but grasses and sedges and some aquatic plants occur in greater amount, and trees that float in during high water or, growing on the deposit, fall and form a part of it are of common occurrence. Many sections of these deposits are exposed. One of the best exposures seen appears in the bank of the Yukon above the Bonasila. Here the brown peat is at least 5 feet thick and contains many spruce logs, which have been broken off flush with the surface of the bank by floating ice. (See Pl. VI, *B*, p. 23.) The logs appear but little rotted. The peat is layered, and some partings of silt or fine sand appear in it, the result of deposition at flood stages of the river when the peat was being formed. No such deposits were seen on any of the tributary streams, although well-consolidated beds of peat over a foot thick are fairly abundant.

In the eddies of the Yukon at high water driftwood often forms piles on the banks which are several feet high, and in 1916 the banks of one or two sloughs were covered with logs two or three deep. Here and there a log was embedded in the bank, but no suggestion

was seen of any such piles becoming thick enough to form on alteration beds of lignite. It appears likely that for the most part these logs are picked up during periods of rising water of successive high-water stages, carried along for a time, and then dropped when the water falls.

None of the deposits of peat appear to have any present value, in view of the abundance of timber in the areas where the peat is found.

IGNEOUS ROCKS.

GREENSTONES.

Carboniferous greenstones occupy large areas in this region, but the rocks are intermingled with sedimentary deposits and are described in connection with the sediments on pages 23-26.

SODA GRANITES, QUARTZ DIORITES, AND DIORITES.

At a number of places below Russian Mission large dikes or sills and still larger bodies of stocklike form have intruded the greenstones and the younger sediments. Such intrusions occur just above the native villages of Kaka and Ohogamut. Between Spruce Creek and the Kuyukutuk there are several larger areas of soda granites, the largest of which forms the core of Pilcher Mountain. The next largest area is at the head of Willow Creek and extends from a point near the forks at claim No. 5 above Discovery almost to the crest of the ridge. Owing to the covering of soil, rock debris, and vegetation it was not determined whether this body is continuous with those to the west at the heads of Owl and Slope creeks and to the east at the head of McNeill Creek. Some of these areas are believed to represent separate intrusive masses and have been so mapped.

Along the bank of Poltes Slough, both at Marshall and a short distance below the mouth of Wilson Creek, there are some sheared gneissoid dike-like bodies that approach quartz diorites in composition, but their original texture has been destroyed and it can not be positively stated whether they are of igneous or sedimentary origin. Similar gneissoid material was seen in the talus southwest of Pilcher Mountain and on the north slope of Mount Okumiak. Along the edges of the intrusive masses at the heads of Slope and Owl creeks evidence of shearing is found in the secondary structure which has been developed. Except as stated above, the texture and appearance of these rocks is essentially granitic, with only an occasional suggestion of gneissoid structure.

At the end of the Survey traverse on Anvik River a small cropping of diorite was seen, but its relation to adjacent rocks was not deter-

mined. Similar rocks were seen in small areas east of Mount Okumiak, and on account of their lithologic similarity to the quartz diorites and the small size of the exposures, they are mapped with the quartz diorites and soda granite.

Considerable variations in mineral composition are found from place to place, but these are believed to be only such as are normally to be expected. Quartz is not abundant, being usually less in quantity than the feldspars, though everywhere present in moderate amount except in the diorites. The feldspars are all plagioclase, of which oligoclase-albite appears to be the most abundant, but it is almost invariably associated with albite or with andesine. Other members of the plagioclase series which may be as basic as labradorite are occasionally seen. Magnetite is usually found in small amounts. Apatite occurs in some of these rocks, especially in those in which there are graphic intergrowths of quartz and feldspar. Biotite is less common than hornblende or pyroxene. Secondary minerals have developed at the expense of the feldspars and ferromagnesian minerals and include epidote, chlorite, calcite, and green hornblende, which have given most of the rocks a greenish tinge.

These intrusives are all younger than the greenstones, and some if not all of them are younger than the members of the sedimentary series between Windy Point and Marshall, which have been provisionally mapped as Cretaceous. There may thus be two series of igneous rocks of very similar chemical composition; on the other hand, there is a possibility that the sediments mentioned are early Mesozoic and that but one period of igneous activity is represented. It is believed, however, that intrusion occurred during two periods, to the earlier of which belong the gneissoid dike-like bodies near Marshall and the intrusive mass forming Pilcher Mountain, as well as some of the intrusives eastward from Mount Okumiak, and to the later of which are to be assigned the bodies of soda granite near Kaka and Ohagamut, together with some of those near Willow Creek, which are believed to be contemporaneous with the dacite dikes in the Marshall district and in the vicinity of Dogfish village, as well as with the andesite and dacite tuffs and flows farther north. As is stated below these andesites and dacites are probably of early Tertiary age. They show little or no deformation. The fact that some of the soda granites are undeformed, though other rocks resembling them closely in composition and occurring in the same area are much deformed, is taken as evidence of two periods of intrusion, the earlier of which is pre-Cretaceous. This conclusion is supported by the occurrence of grains of oligoclase-andesine and pebbles of vein quartz in the Cretaceous sandstones and conglomerates on the Andreafski. The feldspar must have been derived from a pre-Cretaceous medium-silicic

rock, such as a diorite or quartz diorite, and the vein quartz was derived from veins accompanying the intrusive. Such quartz veins appear at the bluff below Marshall. They have suffered deformation comparable in amount with that suffered by some of the diorites and granites, and it may reasonably be inferred that the veins accompanied these intrusives.

The degree of metamorphism and the fact that some of the Cretaceous sediments were derived from rocks of similar composition therefore appear to justify the assumption that some of the soda granites and the quartz diorites are pre-Cretaceous in age and may be correlated with the late Middle Jurassic quartz diorites in the Talkeetna Mountains described by Paige and Knopf¹ and may represent the great granodiorite intrusion which occurred along the Pacific coast and along the axis of the Alaska Range at about that time.²

DACITES AND ANDESITES.

The later igneous rocks north of Anvik are basalt, but those south and west of this point appear to be more siliceous, dacite and andesite dikes, flows, and tuffs being found along Yukon, Stuyahok, and Bonasila rivers. The andesites occur mainly as tuffs and flows near the Yukon between Anvik and the mouth of the Koserefski and as flows on the Bonasila and Stuyahok. In the Stuyahok basin dacites were found as glassy flows in undetermined associations with andesite. In the sedimentary area north of Dogfish village and in the vicinity of Marshall numerous dikes of dacite cut the older rocks. Dacite pebbles found on the bars on Andreafski River about 12 miles above its mouth indicate that intrusives of this type occur also west of the Marshall district.

On account of their close associations the dacites and andesites in the Stuyahok basin could not be separately mapped, although it is recognized that many essential differences exist between these rock types. Both are porphyritic, but there is a wide range in groundmass texture, that of some of the dacite flows being glassy and that of the dikes being distinctly granular. Between these two are gradational textural phases. For the most part the andesites are porphyritic, with microgranular groundmass.

The andesites are dark gray, some of them with a green tinge, and many of them can not readily be distinguished from basalts. It is believed, however, that as a rule they weather in lighter colors than the basalts. A lighter gray, in places tinged with light green,

¹ Paige, Sidney, and Knopf, Adolph, *Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska*: U. S. Geol. Survey Bull. 327, p. 20, 1907.

² Brooks, A. H., *The geography and geology of Alaska*: U. S. Geol. Survey Prof. Paper 45, p. 250, 1903.

is characteristic of the dacite dikes, and this coloring, with their porphyritic habit, exhibiting numerous quartz phenocrysts, serves to distinguish them from other igneous rocks found in this region. In the dacite flows the colors are also light, ranging from very pale yellow to a light rusty brown. Fresh surfaces appear gray, locally with a greenish tinge. Quartz phenocrysts are more prominent in the flows than in the dikes, especially on weathered surfaces.

In mineral composition the dacites appear to be the porphyritic equivalents of the soda granites. The most common feldspar is oligoclase, but there is a range from albite-oligoclase to andesine. Pyroxene phenocrysts are prominent on freshly broken surfaces. Under the microscope magnetite is usually found in small grains. Biotite appears in a few places. Secondary alteration products include epidote, chlorite, green hornblende, and calcite, together with sericite from the alteration of feldspars. Andesine, augite, and magnetite are the chief constituents of the andesites except that some contain also numerous grains of olivine, which show a strong tendency to weather to serpentine. Otherwise the secondary minerals are the same as those produced by the weathering of the dacites.

It is not possible to make definite statements as to the age of the dacites and andesites, which are held to be of the same age as the soda granites. There are, however, two points of reference. The dacites have cut the Cretaceous rocks, and the andesites are cut by the basalt dikes, so that if, as has been assumed, the dacites and andesites are of the same age, they were formed sometime between the end of Cretaceous sedimentation and the extravasation of the basalts, which probably occurred in late Tertiary or early Quaternary time.

Similar rocks, to which a Tertiary age has been assigned, occur in the Ruby-Kuskokwim region,¹ and it is believed that they represent a phase of the Tertiary igneous activity which prevailed over western and southwestern Alaska and are to be correlated with the andesites and dacites of the Anvik-Andreafski region.

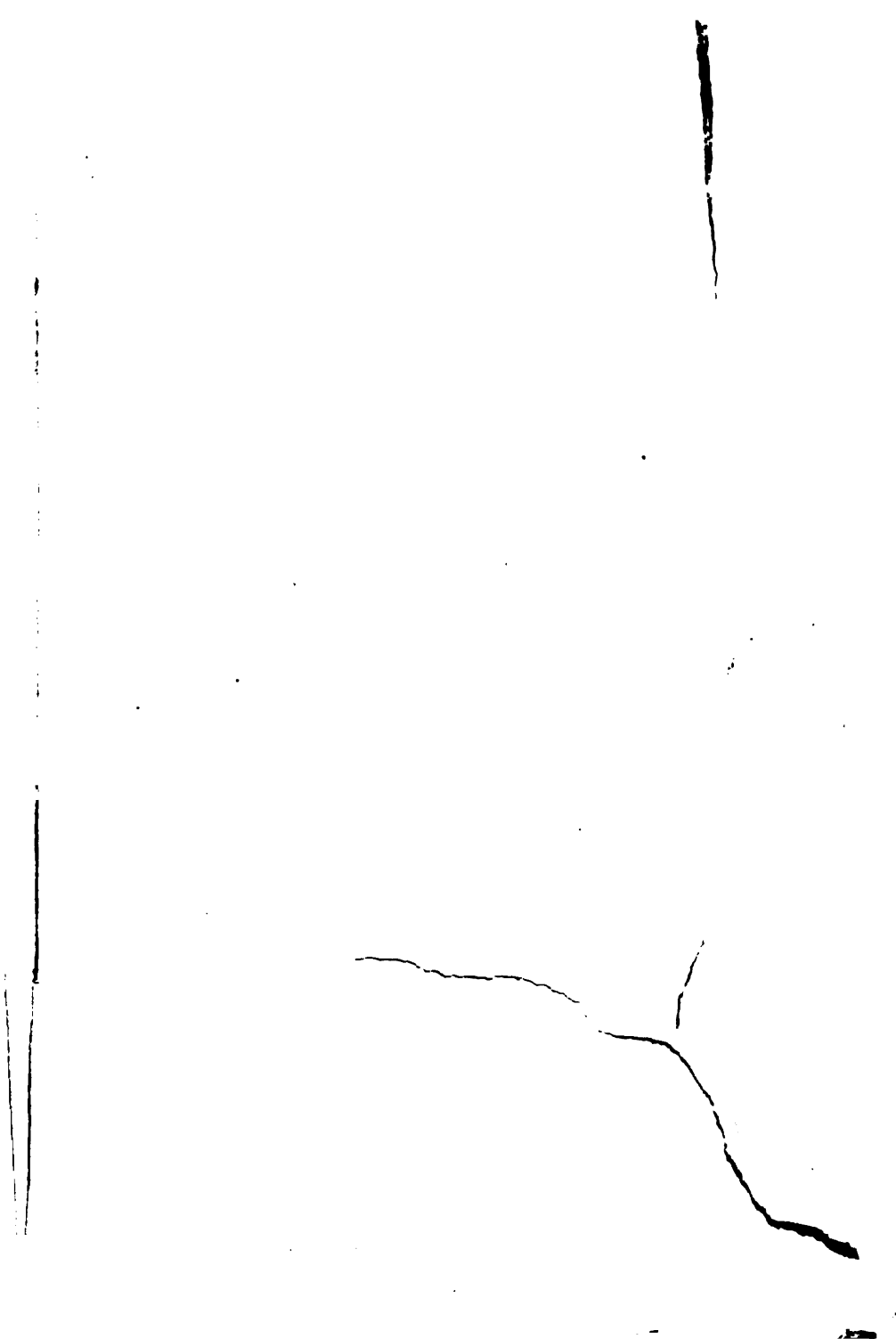
BASALTS.

DISTRIBUTION.

Basaltic flows appear in the low bluffs near Russian Mission and overlie basaltic gravels in the still lower banks at and above Ingrumhart. The hills between Ingrumhart and Engineer Creek consist of lava, and it is probable that other low hills between Engineer Creek and Russian Mission are made up of a continuation of these same

¹ Mertie, J. B., Jr., and Harrington, G. L., The Ruby-Kuskokwim region: U. S. Geol. Survey Bull. — (in preparation).

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of Tertiary age. From these relations the maximum age of the basalts appears to be late Cretaceous or early Tertiary. At and below Russian Mission the flows are nearly horizontal (Pl. VI, A, p. 23) and undeformed, and their attitude indicates that they, as well as the dikes above Holy Cross, have not been influenced by the deformation that probably marked the end of the Eocene epoch. They have not been subjected to any local warping and show no faulting or folding.

Although it is recognized that other explanations are possible, the gravels between the flows above Ingrumhart seem best accounted for by the hypothesis that they represent beach gravels laid down at a stage of the Quaternary inundation and subsequently covered by flows that were poured out during this stage. Some evidence as to the character of the flows is afforded by irregularly rounded weathered lava surfaces at the level of the present river beach a few hundred yards upstream, suggesting the ellipsoids produced by submarine flows. These rounded surfaces may have been produced by other agencies, however, so they afford no positive proof of the littoral origin of the flows.

More definite evidence is at hand regarding the minimum age of the basalts, which in a few localities are overlain by a mantle of Quaternary silts and are therefore older than the silts.

Elsewhere in western Alaska similar rocks are rather widely distributed. Collier's unpublished notes on the geology along the Yukon contain many references to basaltic tuffs, dikes, and flows between Kaltag and Holy Cross. Smith and Eakin¹ state that the vesicular lavas of the Reindeer Hills and Besboro Island "probably mark a connecting link between the well-known volcanic flows of St. Michael on the south and of the Koyuk Valley on the north." Moffit² describes considerable areas of basalts on Seward Peninsula in the valleys of Kuzitrin, Noxapaga, and Koyuk rivers. Some of these flows show very fresh ropy surfaces, which have been only slightly affected by weathering. The age of the youngest effusives is considered to be Pleistocene or late Pliocene, but that of the older flows is more doubtful, because the age of the youngest sedimentary rocks, upon which they rest, has not been determined.

It thus appears that volcanic activity extending over a considerable period of time has occurred not only in the Anvik-Andreafski region but in other regions farther north. The evidence at hand shows that some of the eruptions were separated by considerable intervals of erosion, yet it seems unlikely that in any one locality

¹Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449, p. 72, 1911.

²Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 247, pp. 31-35, 1905.

volcanic activity occurred even spasmodically throughout the period between the times of extravasation of the oldest and youngest lavas. More probably in each locality volcanic activity was confined to a relatively short period and therefore was not exactly synchronous with the activity at other centers.

Criteria are lacking at most of the localities to determine the time at which the lavas were extruded, and it is only possible to say that although they may have been extruded in late Cretaceous, Tertiary, or Quaternary time it appears probable that most of them are late Tertiary or early Quaternary.

GEOLOGIC HISTORY.

Too many facts are missing to permit the writing of the complete geologic history of this region. Fossils give only a single point of reference upon which an outline may be drawn, and all other historical data must be obtained from lithologic relations, from the structure, and from the amount of metamorphism of the rocks within the region, or, if these facts are lacking, by correlation with formations outside the region. Nevertheless, an attempt is here made to summarize such points as are known or may be surmised from the studies that have been made in this and near-by parts of Alaska.

PALEOZOIC TIME.

Nothing is known of the history of this region prior to late Carboniferous time. At that time at least a portion of the region was a land surface upon which flows were poured out, while in the near-by marine basins were laid down deposits consisting largely of tuffs, which in places alternate with conglomerates, sandstones, and even argillitic rocks. These deposits afford an indication of the changing relations of land and sea areas while sedimentation was going on.

In other portions of Alaska¹ a crustal movement took place at the beginning of the Permian epoch, and the pre-Cretaceous movement in this region may well have occurred at the same time. The result of this movement was a general east-west structural trend which is indicated by the general trend of the greenstone areas.

MESOZOIC AND EARLY CENOZOIC TIME.

The extent of the Permian orogenic movements is in doubt, but in the absence of known Triassic or Jurassic sediments it seems likely that they produced ranges of considerable elevation.

Through early Mesozoic time destructional processes were active. Periods during which there were extensive movements, accompanied by granitic intrusions, alternated with periods of quiescence in which erosional agencies were active in reducing the land surface to base-

¹ Brooks, A. H., *op. cit.*, p. 265.

level. Neither marine nor terrestrial deposits of early Mesozoic age are known, so that if such deposits were formed they have been destroyed by erosion. At the beginning of the Lower Cretaceous epoch this part of Alaska was a land surface of moderate relief, across which many broad valleys extended in a general easterly or northeasterly direction. In some of these valleys in adjacent regions subsidence had occurred and marine sediments were being laid down. Between the Lower and Upper Cretaceous epoch extensive diastrophism occurred, resulting in some folding of the earlier sediments and in the Anvik-Andreafski region in the formation of depressions or embayments in which sedimentation took place. It is inconceivable that the submergence of the lowlands was catastrophic, for the amount and texture of the material contained in the Upper Cretaceous sediments preclude anything but a near-by source for much of it, and the occurrence of ripple marks, cross-bedded sandstones, and fresh and brackish water fauna, locally in close association with a fossil flora, indicate littoral and estuarine conditions of deposition over much of the region. The almost universal occurrence of conglomerates along the contact with older rocks is similarly indicative of a sea that slowly encroached upon the land area. Periods of quiescence or even of slight emergence alternated with the periods of subsidence, and thus were formed the basins in which a rank vegetation flourished and was preserved to be converted into beds of coal. These conditions persisted until late Cretaceous or early Eocene time. Sedimentation was then interrupted by igneous activity, but the sediments of normal types that are in places intercalated with the basaltic flows and breccias indicate that the volcanism was not everywhere continuous. In other places there were mountain-forming movements which resulted in great deformation of the Cretaceous beds and superposed a second deformation and cross folding upon the older rocks. With this great diastrophic movement was associated the intrusion of many dikes and larger masses of soda granite along lines of weakness. Auriferous mineralization attended the intrusion. Before the movements ceased, probably in Eocene¹ or early Miocene time, the earlier flows had also been subjected to some deformation.

QUATERNARY PERIOD.

A rather complex series of events marks the history of the region during Quaternary time. At the beginning of this period the surface stood at a somewhat higher elevation than now, and the base level of erosion was lower, so that many of the streams were able to carve deeper valleys in bedrock than those they now occupy. It

¹ Brooks, A. H., *op. cit.*, p. 266.

appears likely that the stream systems had become well established and a fairly mature topography had been developed.

At some time in this stage of erosion there was an extravasation of basaltic lava which materially altered the courses of some of the larger streams, possibly including the Yukon itself or its predecessor. Such is the interpretation of the occurrence of flows between Russian Mission and Ingrumhart.

That the period of extrusion of the lavas was long is made manifest by the occurrence above Ingrumhart of an alternation of flows and of gravel beds in which the pebbles consist of basalt derived from the flows. The gravels may be either river borne or of marine origin. If the former, mature topographic forms may have been developed at this stage; if the latter, they mark the beginning of the succeeding stage in the cycle of events, when there was a subsidence of the land surface of at least 600 feet and possibly much more. It is impossible to state how much higher than its present elevation the land stood at the beginning of the period of subsidence, but that at the end of this period the sea occupied a position 600 feet or more above its present level is clearly indicated by the wave-cut terraces occurring at this elevation, and the unconsolidated deposits below it.

It is believed that this inundation progressed rather steadily and that emergence from the sea was almost equally continuous. As to the duration of this period of inundation little field evidence was found, except in so far as the extent of the terraces then developed is a marker of the length of time taken to form them. These terraces are not extensive anywhere along the Yukon, although traces of them at 600 feet appear more or less clearly on almost every ridge that rises above this elevation, and lower benches of less extent are occasionally seen. On the Anvik below the mouth of Yellow River their best development appears to be between 400 and 500 feet. On the lower half of the Stuyahok the most conspicuous bench appears between 300 and 400 feet. On both the Anvik and the Stuyahok the 600-foot terrace is not so pronounced, although it may be noted on some ridges. (See Pl. I, in pocket.)

To this submergence are due the drowning of the lower portions of practically all the valleys and the formation of the delta deposits which are found throughout the region.

The lack of corroborative fossil evidence as to marine inundation is to be accounted for mainly by two facts. Brackish-water invertebrates whose structure favors fossilization are few in number and, like marine species, might find difficulty in migrating to keep pace with the inundation. The conditions which have prevailed through-

out most of the deposits since emergence have tended to destroy rather than to preserve evidence of animal life. Confirmation of the hypothesis of marine inundation during Quaternary time is therefore to be sought from physiographic details, rather than from fossil evidence.

Emergence after this inundation probably took place very slowly, although it went on at a fairly uniform rate, for few terraces remain to mark stages at which there may have been a long-continued cessation of movement. During the period of emergence there was more or less reworking of the unconsolidated sediments above and along the strand line, and the finer material was carried to successively lower levels. The depressions formerly occupied by the streams were thus gradually filled with silts and fine sands, while the higher portions of the former land surface were again exposed.

During the later part of the Quaternary period there has been little if any relative change of level. The most important geologic event of which evidence is afforded by the present topographic forms is stream adjustment to the new base-level of erosion, through the removal and redeposition of the earlier Quaternary sediments.

Some of the details of adjustment are worthy of note, as they may throw light on the form of possible placers in the larger streams. Keeping pace with the relevation of the land surface to approximately its present position, the larger streams rapidly cut channels in the unconsolidated silts and fine sand in adjustment to the new base-level of erosion. This base-level was then probably considerably lower than at present, for the Yukon, like other large rivers, tends to aggrade in its lower course and has raised its own base-level of erosion and that of its tributaries. The tributaries in turn have filled in their channels in adjustment to the gradually rising base-level.

Where the streams flowed through unconsolidated material the gradients were low, but in their headward portions, above the level of inundation, gradients had been established in bedrock in adjustment to a lower base-level before inundation and were accordingly much steeper. In consequence there was a distinct change in grade where the streams left their bedrock courses and flowed across the silts. Erosion has tended and is tending to restore normal grades throughout their courses, but there still appear to be some streams in which complete adjustment has not yet been reached. In their lower courses erosion consists of a minor amount of lateral cutting of the high silt banks and the migration of meanders. In their upper reaches, where erosion is most active, the elevation of base-level has probably caused no difference in the type of cutting going on, although the amount has been decreased.

A great change, however, has taken place at the points where the streams left bedrock to flow in channels in the silts. Because of the change of grade at these points gravels were deposited there, decreasing the grade above but increasing it below and permitting the transfer of gravels farther and farther downstream. In this way there have been built up within the silts gravel-bottomed channels over which the streams now flow.

Many factors have entered into the location of the present course of the Yukon. A striking feature is the lack of hills on the left bank, and their presence, except where tributaries enter, on the right bank. This feature has been noticed on many northern rivers and is explained by Eakin¹ as being due to deflection to the right caused by the earth's rotation. As the Yukon is an aggrading stream, its channel is constantly changing, and it swings back and forth across its flood plain, but nevertheless the erosion on the right bank is distinctly apparent and appears to control the course of the river. Many channel changes have occurred in the last 20 years. Poltes Slough has been used as the steamboat channel for only a few years, and only in the last year or two have some of the large boats used Cross Slough instead of the channel around the Devils Elbow. Other changes have occurred near Holy Cross and elsewhere. At the site of old Anvik, $1\frac{1}{2}$ miles above Anvik, there is a distance of about 125 feet between Yukon and Anvik rivers, and this distance is constantly decreasing, as both rivers are now cutting at this point. In 1916 the cutting amounted to nearly 20 feet, so that apparently the remaining narrow neck will be cut through in a comparatively short time and the mouth of the Anvik will be at this point rather than at Anvik. At Holy Cross also the amount of cutting may be directly measured. In 1916 it is said to have been 30 feet, and in previous years it had been as much or more, necessitating the moving of many of the buildings that were near the water front. On the other hand, deposition appears to be going on at Russian Mission, although it lies just below one of the narrowest stretches of the river.

One of the peculiar erosion features seen along the Yukon is the occurrence of numerous small semicircular embayments in the shore lines, in which trees still stand but are partly submerged. This is well illustrated in Plate V, A (p. 22); only the tops of the trees in the center are visible, and those on either side are toppling into the water. Below Holy Cross these embayments are especially numerous. They range in radius from a few feet up to about 100 feet. They have probably been formed by the undercutting of eddies at stages of high

¹ Eakin, H. M., The influence of the earth's rotation upon the lateral erosion of streams: Jour. Geology, vol. 18, pp. 435-447, 1910.

water in the spring. Roots and frost prevent erosion at the surface but do not prevent undermining, and as the water subsides the entire undermined area drops and is partly submerged. Each of these areas is comparatively small, but in the aggregate the amount must be large and represents a mode of stream erosion which must be considered.

At elevations above the direct influence of stream erosion other processes have been active. Weathering is hastened by the comminution produced by great variations in temperature and by the extremely effective work of frost. The transporting agent that carries most of the material produced in this way to the lower levels, where it is reworked by the streams, is solifluction rather than running water, as in warmer climates. Solifluction on sloping surfaces is accomplished by the heave and thrust of frost and by gravity, resulting in the characteristic hillside forms that show lobate waves and from a distance have the appearance of flows of some extremely viscous substance. For the most part these lobate forms are characteristic where the rock detritus is fairly fine. Where the frost-riven rock breaks into large angular boulders, solifluction produces distinct topographic forms called altiplanation terraces by Eakin,¹ who has described the processes by which they originate. They resemble wave-cut terraces in outline (see Pl. V, *B*), and may not be readily distinguished from such terraces at a distance, but careful mapping (Pl. I) reveals the fact that terraces on adjacent ridges are not at the same elevations and are separated by different intervals. Furthermore, many of them have the appearance of having been tilted, and a terrace may be tilted in the opposite direction to one below it, thus precluding the hypothesis that they are wave cut. A lack of water-worn pebbles on the terraces also supports the inference that they originated in some way other than by water action.

These terraces are very conspicuous in most of the areas of igneous rocks and in some areas of the sedimentary rocks. Their formation appears to be favored by certain conditions of vegetal growth, for so far as known they do not appear below timber line, although, as in the vicinity of Marshall, they extend down very close to it. Solifluction processes may have acted upon land forms resulting from inundation, which, it has been assumed, extended to an elevation of about 600 feet above present sea level, but no clear evidence of this is at hand.

The present topographic forms are the resultant of all the forces which have been at work to carve them, and it is largely through these forms that the Quaternary history of the region has been interpreted. Each force has acted and is acting to produce definite forms, but such forms have been modified by many other forces, and the

¹ Eakin, H. M., The Yukon-Koyukuk region, Alaska: U. S. Geol. Survey Bull. 681, pp. 78-82, 1916.

present configuration of the land surface has been produced by the agencies which have been described. Erosion has been the dominant factor, and the effects of sedimentation are only local.

MINERAL RESOURCES.

HISTORY OF MINING DEVELOPMENT.

On the discovery of gold at Dawson and at Nome there was an influx of prospectors, who left few of the readily accessible creeks anywhere in Alaska unprospected. Yukon River was the main highway for these men from one camp to another and from the upper river points to St. Michael and Nome. The Anvik portage gave a shorter route to St. Michael than the Yukon and was followed by some. Naturally enough, too, the bars on the Anvik were panned. Colors of gold were found but apparently never in sufficient quantity to warrant mining, and the prospectors sought other localities to work. Almost every year, however, there has been some one prospecting on the Anvik, the Andreafski, and streams between these rivers. In part the prospectors were men who devoted most of their time to trapping, but others had a grubstake sufficient to permit them to devote their entire attention to the search for gold. As a result of their work gold has been found in several places. On the Anvik there are said to be deposits along bars containing gold in paying quantities, but up to 1916 no effort has been made to mine it. Gold colors are said to be obtainable in panning on Stuyahok, Kako, Kuyukutuk, and Andreafski rivers and Mountain Creek, as well as on some of the small creeks emptying into the Yukon near Tuckers Point. No mining has been done on these streams.

The outcrop of metamorphic rock on Peltes Slough, at the present town of Marshall, was noticed by some of the early traders and prospectors on the Yukon, and some desultory prospecting was done on Wilson Creek and on streams flowing into the Kuyukutuk. It was not until July 15, 1913, however, that gold was discovered on Wilson Creek by E. L. Mack and Joe Mills. Claims were staked by these men, and a few days later others were located by Andrew Edgar and A. C. Rohde. A stampede followed, and Wilson Creek and its tributaries were quickly covered with claim locations. Late comers were forced to cross the divide and located claims on Willow Creek and other tributaries of Spruce Creek.

The claims had to be recorded at St. Michael, so that many of them were unrecorded and title to them was lost. On October 25, 1913, a miners' meeting was held and G. M. Pilcher was elected local recorder, but until the Wade Hampton mining precinct was established, with the recorder's office at Marshall, it appeared advisable

to many to make their titles secure by recording both with the local recorder and at St. Michael.

Assessment work for 1913 was not done on many of the claims lying outside of the Wilson Creek valley, and title to them was lost. Prospecting during the winter of 1913 and mining operations early in 1914 gave proof of the presence of gold in paying amounts on Wilson Creek. This stimulated prospecting on other streams near by and led to the discovery of gold on Willow Creek by W. C. Blanker, Ben Blanker, and Robert Barr. Discovery claim, the Bumblebee (corresponding to "No. 1 below"), and "No. 2 below" were staked June 17, 1914. Assessment work and some prospecting was done on these and other claims on Willow Creek, but no gold was obtained from them in 1914.

The shortness of Willow Creek made it at once apparent that the source of gold in the placers was not far distant. Vein quartz carrying free gold was found in the talus on the east slope of the valley about even with claims Nos. 5 and 6 above Discovery, and the veins from which this talus came were staked as lode claims by Thomas Plunkett August 8, 1914.

The first production of placer gold was made in 1914, when about \$15,000 was obtained from two properties on Wilson and Disappointment creeks. In 1915 the output was about \$25,000, mostly from two claims on these creeks, but the list of producers also includes four claims on Willow. A small sample shipment of ore was also made from the lode claims on Willow Creek. In 1916 the gold production was \$270,000 from two claims in the Wilson Creek basin and from seven claims on Willow Creek. Preliminary estimates give the production in 1917 as \$425,000, practically all from six claims on Willow Creek.

The boundaries of the Wade Hampton mining precinct are defined as beginning at a point on Bering Sea between Pastol Bay and Yukon River and following the height of land, which separates Yukon River and Bering Sea drainage, to the one hundred and sixty-first meridian, thence south to a point within 5 miles of the Kuskokwim, thence paralleling the Kuskokwim at a distance of 5 miles from it to the sixtieth degree of north latitude, thence following this parallel to Bering Sea, thence along the coast of Bering Sea, including the adjacent islands, back to the point of beginning.

ECONOMIC FACTORS AFFECTING MINING.

Timber is fairly plentiful for such mining operations as have been conducted. On Elephant and Disappointment creeks fuel could be procured for a time from the bottoms of the valleys along these

streams. Extensive operations, using steam power, would necessitate hauling wood from the valley of Wilson Creek. Alders are the only trees found on Willow Creek above claim No. 2 below Discovery, and consequently all the fuel used for producing power is obtained from the gentle foot slope between Spruce Creek and the hills. This wood costs \$5 a cord to cut, and by the time it is laid down at the mine plant ready to use there is an additional charge of \$5 to \$7 for labor and hauling.

Wages are about the same in this region as at other interior Alaska points. Miners were paid \$5 a day and board in 1916, but in 1917 this was increased to \$6 and board; hoistmen, blacksmiths, and cooks receive \$7 and board. Two shifts of eight hours are employed by the larger plants, but the smaller plants work only one shift. In 1916 employment was given to everyone who wished to work when there was a full sluichead of water. Natives are employed around the camp but do no mining. They are paid \$2 to \$3 a day.

The camp on Willow Creek is very accessible. About 3 miles from the camp, Spruce Creek flows into a small lake, which empties through a slough into the Yukon and rises and falls with that stream. Supplies may be brought to the landing on the lake by gasoline boats or in scows, and one of the smaller steamboats also brought a barge load of lumber up to the lake. The freight rate from Marshall to the landing, about 8 miles by boat, is \$15 a ton. From the landing the rate in 1916 was \$30 a ton to the lower claims on the creek and \$40 a ton to points as far up as "No. 5 above." The winter rate is probably much lower. The rate on general merchandise from Seattle to Marshall, by way of St. Michael, was \$45.50 a ton.

In 1916, on account of traffic conditions, there was a scarcity of some commodities at Marshall. The following prices were paid for staples on the creek:

Flour	per hundredweight	\$10.00
Bacon	per pound	.37
Coffee	do	.75
Tea	do	1.00
Beans	do	.12
Rice	do	.12½
Sugar	do	.13½
Butter	do	.67½
Reindeer meat	do	.25-.30
Beef	do	.45-.50
Potatoes	do	.07½

Lumber was difficult to obtain until a barge load was brought down from Ruby. This sold at \$80 a thousand at the lake.

GOLD PLACERS.**WILSON CREEK.**

Until the summer of 1916 most of the mining in the vicinity of Marshall had been done on Wilson Creek and its tributaries. In the spring of 1916 a small dump was taken out on Elephant Creek, and early in the summer considerable ground was worked at the mouth of Disappointment Creek. At the time of the writer's visit, about the middle of August, there was no one working in the Wilson Creek basin.

Mining had been done by underground methods on claim "No. 5 above" on Elephant Creek, although the ground is comparatively shallow. It is understood that a hydraulic plant is to be installed, the water to be obtained from the headwaters of this stream. The ground on claims above and below No. 5 will be stripped and mined by hydraulic methods.

The workings on Wilson and Disappointment creeks have been confined to about two claims at the mouth of the latter, over a maximum width of about 300 feet. The gravels containing gold in quantities sufficient to justify mining appear to have been irregularly distributed, as work was done at several spots separated by unworked ground. Open-cut methods were employed. These deposits are apparently not over 10 or 12 feet deep to bedrock. The upper portion is composed of 2 to 3 feet of soil and vegetable matter, and this with some of the underlying gravel was stripped off by groundsluicing. The lower stratum of gravel containing the gold was shoveled into sluice boxes. It is said that holes sunk at the mouth of Disappointment Creek failed to reach bedrock at a depth of 35 feet. They were then abandoned on account of water coming in. No mining has been done in the deeper gravels of Wilson Creek itself.

The principal mineral found in the concentrates is hematite, probably coming from a band farther up the creek, which is believed to be the weathered outcrop of a pyritized sedimentary bed. In addition a small amount of magnetite occurs in the octahedral form characteristic of this mineral. A specimen of a few grains of a white metal from the creek sent to the Survey for determination was found to be platinum.

The bedrock is of sedimentary origin. It was not seen in the creek bed, but slates and conglomerates, together with fine grits, appear along the south bank of Wilson Creek just above Disappointment Creek, and these rocks, together with some dark-gray cherts, make up most of the gravels. Some pebbles are derived from dikes that cut the sedimentary rocks and form the igneous rocks at the head of the creek. The gravels are mostly small and well-rounded

pebbles, 8 inches being about the average diameter of the largest cobbles seen. The finer material of the gravels is partly ferruginous, and, although it disintegrates readily in the sluice boxes, on exposure to the air it hardens and cements the larger pebbles into a conglomerata.

WILLOW CREEK.

Willow Creek heads against Disappointment Creek, and the divide is about 700 or 800 feet in elevation above the claims on which most of the mining has been done. Mining has been confined to the west fork of the creek and to the claims from No. 2 below to No. 5 above Discovery; the latter claim covers some ground on the western branch of the small forks near the head of this stream. Some prospecting has been done on "No. 6 above" and on other claims below "No. 2 below," but in 1916 development had not progressed sufficiently to warrant the undertaking of mining operations. Prospecting on claims below "No. 2 below" during the spring and summer of 1917 is said to have resulted in the discovery of deposits rich enough to work.

Two small plants were operating on "No. 5 above," the material being shoveled into sluice boxes. Prospecting was being done on Nos. 3 and 4 above Discovery, and some mining was done on these claims in 1917. Power plants were working on "No. 2 above," the upper half of "No. 1 above," and the upper half of Discovery. On Nos. 1 and 2 above Discovery the auriferous gravel is wheeled in barrows to a bucket and then hoisted to lines of sluice boxes on the hillside. A portion of the stripping is done in the same way, but some of the overburden is removed by sluicing.

The plant operating on the upper half of Discovery in 1916 worked the lower half of "No. 1 above" in 1917. As these claims lie below that portion of the valley that has steep walls (Pl. VII, B), the line of sluice boxes was mounted on trestles to provide the necessary grade and dump room for tailings. A novel feature at this property is that both stripping and hoisting are done by a slack-line scraper, which is a modification of the drag-line scraper used in other Alaskan mining districts. The bucket has a capacity of a yard and a half. On account of the large size and angularity of the boulders and the extremely uneven and blocky character of the bedrock, some difficulties have been experienced with this equipment. It appears likely that the bedrock will have to be cleaned by hand, as it is on other properties. The conditions of operation on Willow Creek for a scraper of this type are probably as difficult as will be found anywhere else, and its successful operation here would warrant an investigation into the possibilities of its economical use at other Alaskan



A. SINTER CONE OF ONE OF THE SODA SPRINGS NEAR MARSHALL.



B. A PORTION OF THE MINING CAMP ON WILLOW CREEK ABOVE MARSHALL.

camps. The rounded and smaller gravels on Disappointment Creek appear to offer more favorable conditions for such a scraper than is afforded by any of the placer ground on Willow Creek.

During 1915 the most extensive mining operations on Willow Creek were on the lower half of Discovery claim. Operations were continued in 1916, and one shift of men was employed shoveling into the sluice boxes. The sluice-box arrangement differs from that on other properties, and a greater effort is made to save the fine gold. The upper four boxes into which the gravel is shoveled have false bottoms, in which are 2-inch holes, spaced 4 to 6 inches on centers. Below this in the line is a box containing Hungarian riffles, with a 6-inch drop to a mud box. The mud box, like the three sluice-box lengths that follow it, has pole riffles of the usual type. At the other properties on the creek all the sluice boxes carry pole riffles, made either of local spruce poles or, when it is obtainable, of sawed 2 by 2 inch lumber. The lumber riffles are generally faced with 2-inch strap iron.

Mining was done on the upper end of the Bumblebee claim early in the summer of 1916, and a small area of ground was worked out. Operations were then shifted to the claim below, and preparations were made for more extensive mining. A sluiceway had been excavated 8 or 10 feet to bedrock, and boxes were being put in on August 27, when the writer left the creek. The contemplated operations included the sluicing of both the overburden and the auriferous gravels from "No. 2 below" through this line of boxes.

On account of the small drainage basin of the creek, the water supply for the claims lying above Discovery is likely to be somewhat scanty unless there are frequent rains. By the time it reaches Discovery claim even this scanty supply has been somewhat lessened. The operators on Discovery have diverted the water from the East Fork of Willow Creek, and so increased the amount available for this claim and those below it. A ditch from Slope Creek was constructed late in the summer to furnish an additional supply for the mining operations on "No. 2 below."

Discovery claim lies about opposite the front of the range of hills, which marks a distinct change in the topography. Below Discovery claim there is a wide, coalescing apron which slopes gently down to Spruce Creek and the Yukon, as illustrated in Plate VII, *B*. Above this topographic break Willow Creek has a V-shaped valley with walls of fairly steep slope; below it the stream has intrenched itself but little in the frontal apron, across which it flows at a gradient lower than where it is confined within the valley. There appears to be a suggestion of a beach line between elevations of 500 and 600 feet (see Pl. II, in pocket), and the change in the topography occurs at

about 500 feet or somewhat lower. This topographic break may mark the position of a beach, and some evidence has been found near Marshall to confirm the suggestion of the topographic form. Fragments of shells are reported to have been found in 1917 in prospect holes at an elevation of about 450 feet on claims on lower Willow Creek. The widening and somewhat irregular distribution of the auriferous gravels below Discovery may be due in part to beach concentration and in part to changes in the channel of the stream before it had become entrenched in its present course.

The depth to bedrock ranges from about 6 to 16 feet. On "No. 1 above" it is from 12 to 16 feet. The upper half of the deposit consists of soil and angular rock fragments with comparatively little rounded gravel. This is stripped off before mining the lower layers. Gold is found both above and below a clay seam lying about 2 feet from bedrock, and some of the coarsest gold occurs above this seam. The bedrock is extremely rough and blocky, and just above it there are a considerable number of large angular boulders, part of which are talus boulders from the valley slopes and part represent frost-heaved material from the greenstone bedrock. On the lower claims there appear to be more rounded gravels, but the bedrock is similar in character to that on the upper portion of the creek.

The gold is somewhat rough, and some of it appears rather porous. Over half of it is coarser than will pass through an 8-mesh screen. Nuggets valued at \$5 to \$10 are not uncommon in the clean-ups, but few worth over \$20 are found. The very fine gold saved constitutes only a very small percentage of the clean-ups. It is believed that the installation of devices for saving the fine gold would be warranted, as some of the fine gold already saved is flaky and light, and it is quite possible that a greater proportion of this light gold goes through the boxes than is saved in them. Few assays of the Willow Creek gold are available. One of these is said to have given a value of \$18.30 an ounce. The gold passes current at \$17 an ounce.

Magnetite is one of the most common minerals associated with the gold in the clean-ups. Ilmenite occurs in small amounts. Although pyrite may be seen here and there in the greenstone near the head of the creek, little or none is found in the concentrates, oxidation having converted it to hematite. Shot is frequently found in the heavy sands resulting from the clean-up. A few grains of platinum are also said to occur in the concentrates.

OTHER STREAMS.

Anvik River and its tributaries have been prospected ever since 1900, and possibly even before that time. Gold has been found on the bars at numerous localities, but never in sufficient amount to jus-

tify mining operations. It is reported, however, that in the winter of 1916-17 two men were prospecting on this stream and found workable placers, upon which work was being done in the summer of 1917. Platinum in considerable amount is said to occur in association with the gold and is mined with it.

Practically all the other large streams accessible by a poling boat or canoe have also been prospected, but up to the present time no commercial placers have been discovered on them.

GOLD LODES.

The hills in the vicinity of Marshall have been prospected to find the lodes from which the placer gold has been derived. A number of lode claims have been staked in the Kuyukutuk basin, on the north side of the ridge extending eastward from Pilcher Mountain. Little development work is reported as having been done on these claims, and they were not visited. Free-milling gold is reported from quartz veins near the head of Edgar Creek, and claims have been staked there. A number of quartz veins were seen along the crest of the divide between Wilson and Spruce creeks. Claims have been staked to cover most of these veins, but no evidence was seen of work having been done upon any of them except on the east side of Willow Creek near its head.

The group of claims on the east side of Willow Creek, known as the Arnold lode, was staked August 8, 1914, by Thomas Plunkett. The development work consists entirely of open cuts made with a view to determining the size and continuity of the veins, of which a number are exposed. One of the lower veins has been traced along its strike for over 100 feet by a series of trenches, 2 to 6 feet deep, through the talus and slide of the hillside. The vein is from 6 inches to a foot in width and shows free gold in places. Farther up on the slope a cut has been dug about 30 feet into the hill, so that there is exposed a face 12 or 15 feet in height and 3 to 6 feet wide. In this face appears a quartz vein ranging in width from 4 to 8 inches. The minerals in the vein include calcite, pyrite, galena, molybdenite, and free gold. In places the pyrite has oxidized, and the quartz is stained with iron oxides. The vein shows numerous cavities formed by the removal of pyrite and calcite. In some of these cavities small glassy quartz crystals may be seen, together with an occasional rosette of calcite crystals. Some of the dirt from the bottom of the open cut was panned. In addition to the vein minerals mentioned above, the concentrates from panning included small amounts of wulfenite, the yellow to orange-colored molybdate of lead, and anglesite, the white sulphate of lead. Magnetite and the oxides derived from the alteration of iron pyrite are also present in

considerable amounts. The source of the latter minerals is the greenstone country rock, the hanging wall in places showing strong pyritization. Veins near by show a small amount of chalcopyrite, accompanied by the characteristic green stain produced by its oxidation. Similar mineralization has occurred in the quartz veins that appear in the bank of the river at Marshall.

ANTIMONY.

No veins carrying antimony are known within the areas visited, but at Paimiut it was reported that stibnite occurs in the group of hills south of the Yukon, near the Kuskokwim.

MINERALIZATION.

Data regarding the mineralization in this region are not sufficiently complete to justify positive statements regarding the source of the gold, but some inferences concerning it can be drawn. Wherever gold has been found there are also soda granites or porphyritic dacite dikes, many of them of considerable width, and it is believed that the mineralization was consequent upon the intrusion of both the sedimentary and igneous rocks by these granites and dacites. The dacites are similar in chemical composition to the soda granites and differ from them only in having a somewhat finer groundmass and a porphyritic texture. They represent offshoots from the larger igneous masses or were derived from the same sodic granite magma. Both the larger granite masses and the dacite dikes appear to have been concerned in the mineralization. The quartz veining that followed is also related to the intrusions, and much of the gold occurs in the vein quartz, but wall-rock impregnation has also taken place. Besides the gold the sulphides of iron, lead, molybdenum, and copper occur as pyrite, galena, molybdenite, and chalcopyrite, in the veins and mineralized wall rock. These minerals have not been found in the soda granites or dacites but doubtless were formed as a consequence of their intrusion.

SUGGESTIONS FOR GOLD PROSPECTING.

As the mineralization was attendant upon the soda granites and the porphyritic dacites, it follows that streams which drain areas where these rocks appear afford the most attractive field for prospecting. Exposures are few in most parts of the region but may usually be found along the crests of the ridges or here and there along minor streams. The nature of the gravel along bars, however, will afford quite as effectively an indication of the nature of the rocks farther upstream. Vein quartz or pebbles of light-colored granitic or porphyritic igneous rock should be noted. The rocks from which these pebbles are derived are of course not necessarily accompanied by gold,

but, on the other hand, in this region the gold has always been found under conditions which indicate its derivation from these intrusives.

On the upper courses of most of the streams the valleys are comparatively narrow and the depth to bedrock slight, making cross-cutting of the channel fairly easy. On the lower reaches, however, the width is greater, in some places being several miles, and the valley fill is of unknown depth. Prospecting under such conditions, taken in connection with the possibility of changes in the position of stream courses since the concentration of the gold in placers, appears uncertain to yield profitable results.

COAL.

The presence of coal on Anvik River has long been known and is mentioned by Collier.¹ It seems to have been used to a moderate extent by the natives, who formerly employed it in the manufacture of a black pigment. A small amount has also been used for blacksmith coal at Anvik, but so far as known no other utilization has been attempted. The following information regarding these deposits was obtained from Mr. F. H. Kruger, a merchant and prospector at Anvik.

The coal seams crop out about 45 miles above the mouth of Yellow River, or over 100 miles by water from the Yukon; the air-line distance to the nearest point on the Yukon is probably about 35 miles. Anvik River cuts diagonally across the sedimentary series, made up of sandstones, shales, and coal beds, which appear for a distance of about 5 miles along the course of the stream. Both up and down stream from the sedimentary series are rocks of igneous origin. Within the series coal seams appear for nearly a mile along the river, most of the outcrops on the east bank. One seam has a thickness of about 10 feet, and several have a thickness of 2 feet.

Transportation to the Yukon would entail a high expense, as only small poling boats could be used except at high-water stages, when small scows and power boats might be utilized. Transportation overland would prove feasible only if the local market were sufficiently great to warrant the construction of a road, after exploration and development work had proved the extent and quality of the coal.

Coal seams of varying thickness will doubtless be found elsewhere in the areas of Cretaceous rocks. Many fragments of weathered coal were found in the high gravel bank on the east side of Stuyahok River about 45 miles from its mouth. It is likely that these fragments have not been carried for any great distance and that careful

¹ Collier, A. J., The coal resources of the Yukon, Alaska: U. S. Geol. Survey Bull. 218, p. 56, 1903.

prospecting would reveal the seams from which they were derived. Like those on the Anvik these beds when found would probably be of local value only, unless they were of considerable extent and the coal of such a quality as would permit it to compete with other fuels.

At Marshall it was learned that coal occurs on one of the creeks which flows into a slough of the Yukon about 20 miles above Marshall. No information concerning this deposit other than the fact of its occurrence was obtainable.

A narrow band of bituminous shale occurs in the vicinity of the old fort at Andreafski.¹ The Russians attempted to utilize this shale for fuel, but it was too impure to burn well, and the attempt was abandoned. This locality is a few miles down the Yukon from Andreafski, where field work was terminated in 1916, and was not visited by the writer.

MINERAL SPRINGS.

About 7 miles east of south of Marshall and half a mile from the Willow Creek landing are what are known locally as the Soda Springs. Analyses show the mineral content of the waters from these springs to be chiefly calcium and bicarbonate, with considerable iron. Free carbon dioxide is constantly being liberated and bubbles up intermittently in almost all the pools and springs of this group. Some have built up considerable cones, 4 to 6 feet high and 10 to 20 feet wide at the base. (See Pl. VII, A.) The material in these cones consists of lime carbonate and yellow and red iron oxides. At the northern edge of the group is an extensive area covered with granular precipitated oxides of iron, with some lime carbonate, which is rather loose and incoherent, much resembling gas-house cinders. It has built up a deposit thick enough to afford a solid footing, much in contrast with that of the soft, spongy moss-covered areas near by. That very little vegetation grows on the sinter is indicated by the photograph of the cone. (See Pl. VII, A, p. 60.)

Between the main group of springs and the landing are a number of pools of water which in part may represent the overflow from the springs above and in part may be the basins of other springs having a comparatively small flow. The deposits in the vicinity of these pools consist chiefly of lime carbonate and are conspicuous for their white color and scanty growth of vegetation.

The springs are situated at the base of the south frontal slope of the range of hills between Spruce and Wilson creeks. A mantle of vegetation and unconsolidated material so completely covers the surface that it is impossible to determine the nature of the underlying bedrock. It appears likely, however, that the springs occur

¹ Dall, W. H., and Harris, G. D., Correlation papers, Neocene: U. S. Geol. Survey Bull. 84, p. 247, 1892.

near the contact of the Quaternary lavas and the greenstones which make up the ridge to the north. Other springs of essentially similar character are reported as occurring about 12 miles to the east, where the topographic situation and geologic conditions are much the same as at this locality.

Little utilization has been made of these mineral waters. The spring shown in Plate VII, A, was dug down about 3 feet or more from the crest of the cone, and a small basin was dug below the rim of the outlet. This spring flows a few quarts to the minute. The water is carried up to the camp on Willow Creek and used to a small extent as a table water. A few hundred yards to the north another spring has been dug out, the cone leveled off, and a log building erected over it. This building was in use as a saloon, and the basin of the spring served both for cold storage and as a source of carbonated water.

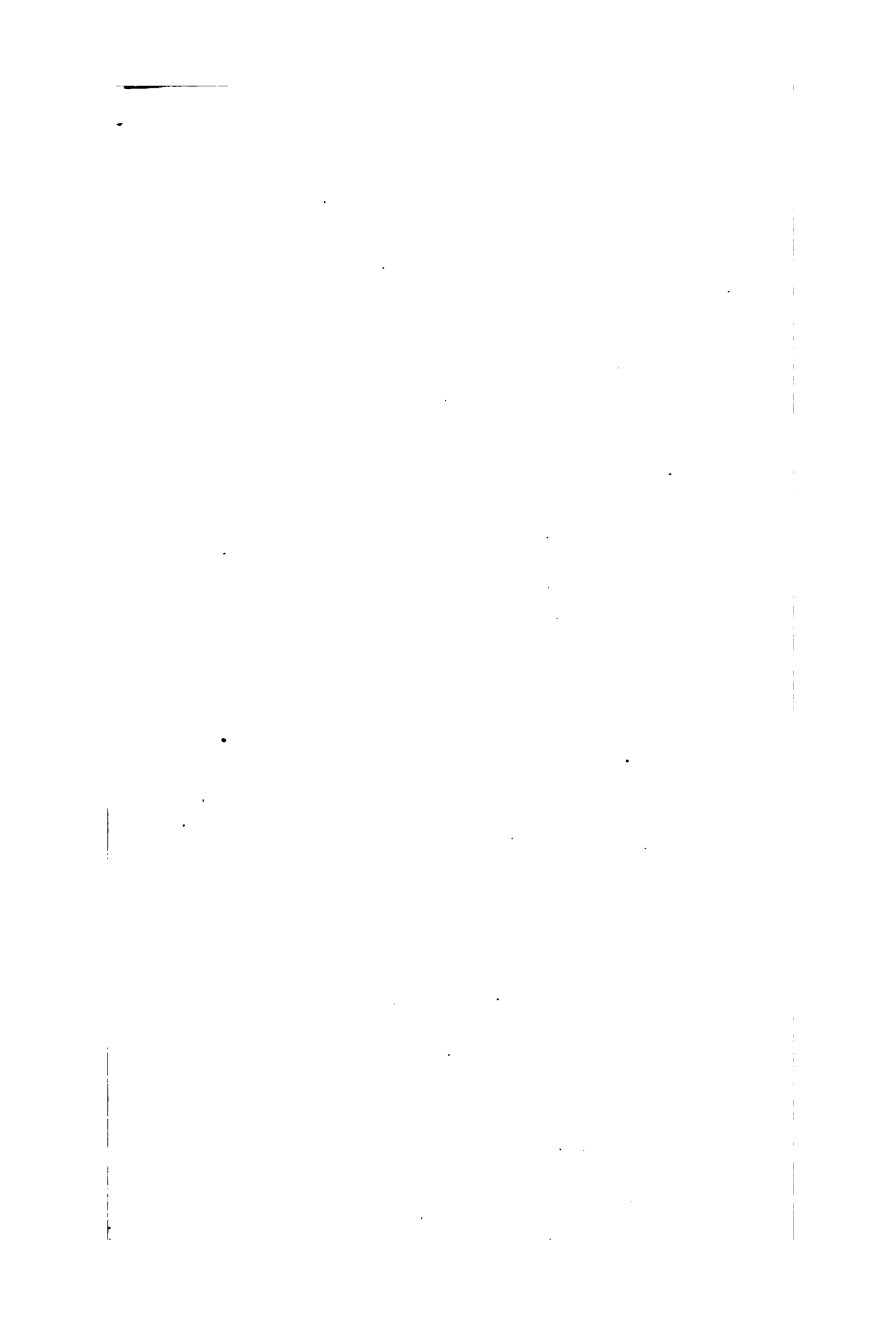
An analysis¹ of this water by R. B. Dole and Alfred A. Chambers gave the following results:

Analysis of water from Soda Springs, near Marshall.

	Parts per million.
Silica (SiO ₂)	40
Iron (Fe)	6.2
Aluminum (Al)	4.0
Calcium (Ca)	366
Magnesium (Mg)	58
Sodium (Na)	32
Potassium (K)	14
Carbonate radicle (CO ₃)	.0
Bicarbonate radicle (HCO ₃)	1,456
Sulphate radicle (SO ₄)	18
Chloride radicle (Cl)	8.1
Nitrate radicle (NO ₃)	Trace.
Total dissolved solids at 180° C.	1,270
Free CO ₂	1,840

Water for analysis was taken from the open spring and so had lost some free CO₂. It is possible that some of the iron may have been precipitated. In precipitating from solution the iron appears to have gone out first, so that even the small percentage shown by this analysis would account for the presence of the iron minerals near the vents of the springs. Iron oxides make up a considerable amount of the sinter but appear to constitute a much larger part of it than they really do, as both the yellow and brown sinter contain considerable lime carbonate, the presence of which is concealed by the color of the iron minerals.

¹ Waring, G. A., Mineral springs of Alaska: U. S. Geol. Survey Water-Supply Paper 418, p. 87, analysis No. 5, 1917.

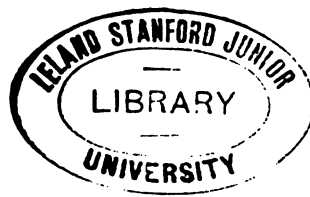


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DEPARTMENT OF THE INTERIOR

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Bulletin 684

BIBLIOGRAPHY
OF
NORTH AMERICAN GEOLOGY
FOR
1917

WITH SUBJECT INDEX

BY

JOHN M. NICKLES



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1918

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BIBLIOGRAPHY OF NORTH AMERICAN GEOLOGY FOR 1917, WITH SUBJECT INDEX.

By JOHN M. NICKLES.

INTRODUCTION.

The bibliography of North American geology, including paleontology, petrology, and mineralogy, for the year 1917 follows the plan and arrangement of its immediate predecessors. It includes publications bearing on the geology of the Continent of North America and adjoining islands; also Panama and the Hawaiian Islands. Papers by American writers on the geology of other parts of the world are not included. Textbooks and papers general in character by American authors are included; those by foreign authors are excluded unless they appear in American publications.

As heretofore, the papers, with full title and medium of publication and explanatory note when the title is not fully self-explanatory, are listed under the authors, arranged in alphabetic order. The author list is followed by an index to the literature listed. In this index the entries in one alphabet are of three kinds—first, subject, with various subdivisions, to enable the specialist to ascertain readily all the papers bearing on a particular subject or area; second, titles of papers, many of them abbreviated or inverted, under their leading words; and third, cross references, which have been freely used to avoid too much repetition. The subjects have been printed in black-faced type, the titles of papers and cross references in ordinary type. As it may not be always obvious which subject headings have been adopted, an outline of those used immediately precedes the index.

The bibliography of North American geology is comprised in the following bulletins of the United States Geological Survey: No. 127 (1732-1892); Nos. 188 and 189 (1892-1900); No. 301 (1901-1905); No. 372 (1906-7); No. 409 (1908); No. 444 (1909); No. 495 (1910); No. 524 (1911); No. 545 (1912); No. 584 (1913); No. 617 (1914); No. 645 (1915); No. 665 (1916); and No. 684 (1917).

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OUTLINE OF SUBJECT HEADINGS.

In the following index the subject headings are printed in black-faced type. An outline of these is here given that it may be quickly seen which subject heading of two or more synonyms has been adopted. Thus "petroleum" and not "oil" nor "rock oil" has been chosen. That the specialist may see at a glance under what headings to find cognate literature, subject headings that are more or less closely related have been grouped together under the following heads: Areal or regional, general, economic, dynamic and structural, physiographic, stratigraphic or historical, paleontology, petrology, mineralogy, underground water. In the index the specific entries under the areal or regional subject headings are alphabetized under these same heads arranged in the same order, namely, general, economic, etc.

AREAL OR REGIONAL.

The States and Territories of the Union, Alabama, Alaska, etc.; The Provinces of Canada, Alberta, etc.; Greenland; Arctic regions; Mexico; the countries of Central America; the West Indies, and the single islands; the Hawaiian Islands.

GENERAL.

Associations, meetings; Addresses; Philosophy; History; Biography; Bibliography; Education; Textbooks.

Surveys; Fieldwork; Excursions; Technique; Cartography.

Classification; Nomenclature.

Geochemistry; Chemical analyses (list); Geophysics; Atmosphere; Radioactivity.

Experimental investigations; Borings; Miscellaneous.

ECONOMIC.

Ore deposits, origin; Contact phenomena.

Gold; Placers; Black sands; Silver; Quicksilver; Nickel; Cobalt; Copper; Lead; Zinc; Iron; Magnetite; Manganese; Tin.

Aluminum; Bauxite; Antimony; Bismuth; Tungsten; Vanadium; Uranium; Carnotite ores; Molybdenum; Chromic iron ore.

Platinum; Palladium; Titanium; Rutile; Rare earths; Monazite; Zircon.

Coal; Anthracite; Lignite; Peat.

Petroleum; Natural gas; Oil shales; Asphalt; Albertite; Gilsonite; Bituminous rock.

Stone; Building stone; Granite; Trap; Bluestone; Limestone; Marble; Lime; Gypsum.

Sand; Glass sand; Silica; Quartz; Quartzite; Sandstone; Gravel; Cement and cement materials; Concrete materials; Road materials.

Clay; Kaolin; Bentonite; Fire clay; Gault; Slate; Shale; Pyrophyllite.

Serpentine; Asbestos; Steatite; Soapstone; Talc.

Precious stones; Diamonds; Sapphires; Turquoise; Tourmaline; Onyx.

Abrasive materials; Corundum; Emery; Garnet; Diatomaceous earth; Tripoli; Volcanic ash; Pumice; Millstones; Whetstones; Novaculite; Feldspar. Phosphate; Apatite; Potash; Alunite; Nitrate; Glauconite; Marl. Salt; Salines; Bromine; Calcium chloride; Borax; Fluorspar. Barite; Strontium; Mineral paints. Arsenic; Fuller's earth; Infusorial earth; Magnesite; Mica; Graphite. Phosphorus; Sulphur; Pyrite. Soils.

DYNAMIC AND STRUCTURAL.

Earth, Genesis of; Earth, age of; Earth, interior of; Earth, temperature of. Volcanism; Volcanoes; Earthquakes; Seismology; Seismographs; Mud volcanoes.

Isostasy; Orogeny; Changes of level.

Magma; Magmatic differentiation; Laccoliths; Intrusions; Dikes; Contact phenomena.

Deformation; Folding; Faulting; Unconformities.

Conglomerates; Concretions; Stalactites; Jointing; Cleavage.

Denudation; Erosion; Coast changes; Coral islands and reefs; Weathering; Caves; Sink holes; Wind work; Dunes; Loess; Landslides.

Glaciers; Glacial erosion; Glacial striae; Potholes; Kettle holes.

Sedimentation; Eskers; Kames; Moraines.

Drainage changes.

PHYSIOGRAPHIC.

Geomorphy; Relief maps.

Plains; Prairies; Peneplains; Valleys; Cirques; Deserts; Alluvial fans; Deltas; Mounds, natural; Sink holes; Karsts; Natural bridges.

Rivers; Stream piracy; Meanders; Falls; Lakes; Swamps; Marshes; Everglades.

Terraces; Beaches; Shore lines.

STRATIGRAPHIC OR HISTORICAL.

Geologic history; Geologic time; Paleogeography; Paleogeographic maps; Paleoclimatology.

Geologic maps; Geologic formations described (list); Tables of formations; Unconformities; Borings.

Pre-Cambrian; Paleozoic (undifferentiated); Cambrian; Ordovician; Silurian; Devonian; Carboniferous; Mesozoic (undifferentiated); Triassic; Jurassic; Cretaceous; Tertiary; Quaternary; Recent.

Glacial geology; Glaciation; Drift deposits; Glacial lakes; Erratic boulders; Ice ages (ancient).

PALEONTOLOGY.

Geographic distribution; Evolution; Restorations.

Vertebrata; Man, fossil; Mammalia; Aves; Reptilia; Amphibia; Pisces; Footprints.

Invertebrata; Arthropoda; Crustacea; Trilobita; Ostracoda; Insecta; Arachnida; Myriapoda.

Mollusca; Cephalopoda; Gastropoda; Pelecypoda.

Molluscoidea; Brachiopoda; Bryozoa; Vermes.

Echinodermata; Echinoidea; Asteroidea; Crinoidea; Cystoidea,

Cœlenterata; Anthozoa; Hydrozoa; Graptolites.

Protozoa; Spongida; Foraminifera.

Paleobotany; Diatoms; Algæ.

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PETROLOGY.

Rocks, origin; Rocks, structural features; Rocks described (list); Igneous and volcanic rocks; Rock-forming minerals; Lava; Oolite; Dolomite; Pebbles.

MINERALOGY.

Minerals described (list); Crystallography; Pseudomorphism; Paragenesis of minerals; Rock-forming minerals; Meteorites.

UNDERGROUND WATER.

Mineral waters; Thermal waters; Geysers; Springs; Mine waters.

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- Aaron slate, Ordovician (?), Virginia, North Carolina: Laney, 608.
- Abbeyville gabbro, Virginia, North Carolina: Laney, 608.
- Ablene limestone, Permian, Texas: Wrather, 1174.
- Admiralty till, Pleistocene, British Columbia: Clapp, 193.
- Agawa formation, pre-Cambrian, Minnesota: Broderick, 119.
- Akron dolomite, Silurian, Ontario: Chadwick, 183.
- Aldridge conglomerate, pre-Cambrian, British Columbia: Drysdale, 303.
- Alger stage, Silurian, Kentucky: Miller, 727.
- Allegheny formation, Pennsylvanian, Ohio: Stout, 1008.
- Allegheny series, Pennsylvanian, West Virginia: Hennen, 451.
- Allensville member, Mississippian, Ohio: Stout, 1008.
- Allensville substage, Mississippian, Kentucky: Miller.
- Allentown limestone, Cambrian, Pennsylvania: Miller, 727, 728.
- Allison formation, Cretaceous, British Columbia: Rose, 880.
- Alpena limestone, Devonian, Michigan: Smith, 967.
- Alta shale, Cambrian, Utah: Tomlinson, 1027.
- Alum Bluff formation, Miocene, Florida: Sellards, 919.
- Alum Bluff formation, Tertiary, Georgia: Shearer, 936.
- Ames limestone, Pennsylvanian, Ohio: Stout, 1008.
- Ames limestone and shale, Pennsylvanian, West Virginia: Hennen, 451.
- Amherst schist, Carboniferous, Massachusetts: Emerson, 321.
- Amsden formation, Carboniferous, Wyoming: Hewett and Lupton, 461.
- Amsterdam limestone, Ordovician, New York: Coryell, 237.
- Anastasia formation, Pleistocene, Florida: Chamberlin, 186.
- Anderdon limestone, Silurian, Michigan: Smith, 967.
- Annabelle shale, Pennsylvanian, West Virginia: Hennen, 451.
- Antrim shale, Mississippian, Michigan: Sherzer, 917.
- Anvil Rock substage, Pennsylvanian, Kentucky: Miller, 727.
- Apalachicola group, Tertiary, Georgia: Shearer, 936.
- Aquila formation, Tertiary (Eocene), Maryland: Miller *et al.*, 730.
- Arcturus limestone, Pennsylvanian, Nevada: Spencer, 975.
- Arkadelphia clay, Cretaceous, Louisiana: Matson and Hopkins, 696.
- Arkansas novaculite, Devonian, Arkansas: Miser, 737.
- Arkona beds, Devonian, Ontario: Grabau, 393.
- Arnheim substage, Ordovician, Kentucky: Miller, 727.
- Arnoldsburg sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Arundel formation, Cretaceous, Maryland: Miller *et al.*, 730.
- Aspermont dolomite, Permian, Texas: Wrather, 1174.
- Astoria series, Oligocene, California: Clarke, 204.
- Athabasca series, pre-Cambrian, Saskatchewan: Alcock, 9.
- Athens shale, Ordovician, Virginia and Tennessee: Raymond, 833.
- Atoka formation, Carboniferous, Arkansas: Miser, 737.
- Aurora sandstone, Mississippian, Ohio: Verwiebe, 1066.
- Austin chalk, Cretaceous, Texas: Hopkins, 486; Matson and Hopkins, 697; Udden and Bybee, 1050.
- Ayer granite, Carboniferous (or later), Massachusetts: Emerson, 321.
- Bad River limestone, Algonkian, Michigan: Smith, 967.
- Baltimore gneiss, pre-Cambrian, Maryland: Miller *et al.*, 730.
- Barnwell formation, Tertiary, Georgia: Shearer, 936.
- Bass Islands dolomite, Silurian, Michigan: Sherzer, 917.
- Bass Island series, Silurian, Michigan: Smith, 967.
- Bayport (Maxville) limestone, Mississippian, Michigan: Smith, 967.
- Bearpaw formation, Cretaceous, Montana: Thom, 1020.
- Bearpaw shale, Cretaceous, Alberta: Dowling, 296.
- Bearpaw shale, Cretaceous, Montana: Collier, 223; Hares, 424; Stebinger, 984; Woolsey *et al.*, 1173.
- Beattyville substage, Pennsylvanian, Kentucky: Miller, 727.
- Becket granite gneiss, Archean, Massachusetts: Emerson, 321.
- Becraft limestone, Devonian, Pennsylvania: Reeside, 841.
- Bedford formation, Mississippian, Ohio: Stout, 1008.
- Bedford shale, Devonian or Carbonaceous, Ohio: Rogers, 875.
- Bedford shales, Devonian, Ohio: Verwiebe, 1067.
- Bedford substage, Mississippian, Kentucky: Miller, 727.
- Beekmantown formation, Ordovician, Michigan: Smith, 967.
- Beekmantown limestone, Ordovician, Pennsylvania: Miller, 728.

- Beekmantown limestone, Ordovician, Vermont: Perkins, 794.
- Belchertown tonalite, Carboniferous, Massachusetts: Emerson, 321.
- Bellevue substage, Ordovician, Kentucky: Miller, 727.
- Bellingham conglomerate, Carboniferous, Massachusetts and Rhode Island: Emerson, 321.
- Bellowspipe limestone, Ordovician, Massachusetts: Emerson, 321.
- Belly River series, Cretaceous, Alberta: Dowling, 296.
- Bennett quartzite, pre-Cambrian, Quebec: Knox, 596.
- Benson conglomerate, Cretaceous, British Columbia: Clapp, 193.
- Benson formation, Ordovician, Kentucky: Raymond, 833.
- Benton formation, Cretaceous, British Columbia: Rose, 880.
- Benton formations, Cretaceous, Wyoming: Ziegler, 1189.
- Benton shale, Cretaceous, North Dakota: Leonard, 633.
- Berea formation, Mississippian, Ohio: Stout, 1008.
- Berea formation, Mississippian, Pennsylvania: Verwiebe, 1066.
- Berea sandstone, Mississippian, Michigan: Sherzer, 917.
- Berea sandstone, Mississippian, Ohio: Rogers, 875.
- Berea substage, Mississippian, Kentucky: Miller, 727.
- Berkshire schist, Ordovician, Massachusetts: Emerson, 321.
- Bernardston formation, Devonian, Massachusetts: Emerson, 321.
- Berne substage, Mississippian, Kentucky: Miller, 727.
- Berwick gneiss, pre-Carboniferous, Maine, New Hampshire: Katz, 546.
- Bessemer granite, pre-Cambrian, North and South Carolina: Keith and Sterrett, 558.
- Bethel substage, Mississippian, Kentucky: Miller, 727.
- Beverly syenite, Carboniferous, Massachusetts: Emerson, 321.
- Biddeford granite, post-Carboniferous, New Hampshire and Maine: Katz, 546.
- Bigby (?) limestone, Ordovician, Kentucky: Phalen, 799.
- Bigby substage, Ordovician, Kentucky: Miller, 727.
- Bigfork chert, Ordovician, Arkansas: Miser, 737.
- Bighorn dolomite, Ordovician, Wyoming and Montana: Tomlinson, 1027.
- Bingen sand, Cretaceous, Arkansas: Berry, 69.
- Birch Creek schist, pre-Ordovician, Alaska: Capps, 174.
- Birdsville stage, Mississippian, Kentucky: Miller, 727.
- Birmingham moraine, Quaternary, Michigan: Sherzer, 917.
- Birmingham shale, Pennsylvanian, West Virginia: Hennen, 451.
- Bisher member, Silurian, Ohio: Foster, 350.
- Black Hand substage, Mississippian, Kentucky: Miller, 727.
- Black River formation, Ordovician, New York: Coryell, 237.
- Black River limestone, Ordovician, Vermont: Perkins, 794.
- Blairmore formation, Cretaceous, British Columbia: Rose, 880.
- Blakely sandstone, Ordovician, Arkansas: Miser, 737.
- Blaylock sandstone, Silurian, Arkansas: Miser, 737.
- Bliss sandstone, Cambrian, New Mexico: Darton, 257, 258.
- Blowout Mountain sandstone, Permian, Texas: Wrather, 1174.
- Blue Hill granite porphyry, Carboniferous, Massachusetts: Emerson, 321.
- "Bolton" gneiss, Carboniferous, Massachusetts: Emerson, 321.
- Bonanza latite, Colorado: Patton, 787.
- Bonne Terre dolomite, Cambrian, Missouri: Buehler, 137.
- Boone formation, Mississippian, Missouri: Buehler, 137.
- Bowden beds, Miocene, Mexico and Central America: Dickerson, 281.
- Boylston schist, Carboniferous, Massachusetts: Emerson, 321.
- Bradfordian series, Devonian, Pennsylvania: Verwiebe, 1067.
- Braintree slate, Cambrian, Massachusetts: Emerson, 321.
- Brandywine formation, Tertiary (Pliocene), Maryland: Miller *et al.*, 730.
- Brannon cherty member, Ordovician, Kentucky: Phalen, 799.
- Brassfield substage, Silurian, Kentucky: Miller, 727.
- Breathitt stage, Pennsylvanian, Kentucky: Miller, 727.
- Brecksville formation, Mississippian, Ohio: Verwiebe, 1066.
- Bridgeton formation, Quaternary, New Jersey: Salisbury and Knapp, 890.
- Brimfield schist, Carboniferous, Massachusetts: Emerson, 321.
- Broncho Mountain granite, Colorado: Crawford and Worcester, 238.
- Brookline conglomerate member, Carboniferous, Massachusetts: Emerson, 321.
- Brownstown sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Bruce conglomerate, pre-Cambrian, Ontario: Quirke, 827.
- Bruce limestone, pre-Cambrian, Ontario: Quirke, 827.
- Bruce series, pre-Cambrian, Ontario: Quirke, 827.
- Brunswick conglomerate, Triassic, Pennsylvania: Jonas, 537; Miller, 728.

- Brunswick shale, Triassic, Pennsylvania: Jonas, 537; Miller, 728.
 Brush Creek limestone, Pennsylvanian, Ohio: Stout, 1008.
 Brush Creek limestone and shale, Pennsylvanian, West Virginia: Hennen, 451.
 Buckingham series, pre-Cambrian, Quebec: Wilson, 1153, 1154.
 Buena Vista member, Mississippian, Ohio: Stout, 1008.
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 Buffalo sandstone, Pennsylvanian, West Virginia: Hennen, 451.
 Buffalo Hill sandstones, Permian, Texas: Wrather, 1174.
 Bulkley intrusives, Tertiary (?), British Columbia: DoImage, 292.
 Bull Lake Creek formation, Cambrian, Wyoming: Branson, 112.
 Bullwagon dolomite, Permian, Texas: Wrather, 1174.
 Burgoon formation, Mississippian, Pennsylvania: Verwiebe, 1066.
 Byer member, Mississippian, Ohio: Stout, 1008.
 Byer substage, Mississippian, Kentucky: Miller, 727.
 Calaveras formation, Carboniferous, California: Moody, 742.
 Calvert formation, Tertiary (Miocene), Maryland: Miller *et al.*, 730.
 Cambridge limestone, Pennsylvanian, Ohio: Stout, 1008.
 Cambridge slate, Carboniferous, Massachusetts: Emerson, 321.
 Camden chert, Devonian, Tennessee: Dunbar, 306.
 Campbell Creek limestone, Pennsylvanian, West Virginia: Hennen, 451.
 Camp Nelson substage, Ordovician, Kentucky: Miller, 727.
 Canajoharie shale, Ordovician, New York: Raymond, 833.
 Cantwell formation, Tertiary, Alaska: Capps, 174.
 Cape Elizabeth formation, Carboniferous, Maine: Katz, 546.
 Cape May formation, Quaternary, New Jersey: Salisbury and Knapp, 890.
 Carbondale formation, Pennsylvanian, Illinois: Brokaw, 121; Cady, 151; Hinds, 469, 470; St. Clair, 886.
 Carlile shale, Cretaceous, Wyoming: Hares, 424.
 Carmelo series, Cretaceous, California: Hawley, 431.
 Carolina gneiss, Archean, North and South Carolina: Keith and Sterrett, 558.
 Carrizo formation, Tertiary, California: Vaughan, 1064.
 Casco Bay group, Carboniferous, Maine: Katz, 546.
 Caseyville substage, Pennsylvanian, Kentucky: Miller, 727.
 Cassville plant shale, Permo-Carboniferous, West Virginia: Hennen, 451.
 Castle formation, Permian (?), Texas: Parch, 811.
 Catahoula sandstone, Oligocene, Alabama: Hopkins, 488.
 Catahoula sandstone, Oligocene, Louisiana: Matson, 695.
 Cathedral formation, Cambrian, British Columbia: Walcott, 1078, 1079.
 Catskill, Devonian, New York: Verwiebe, 1067.
 Cedar District formation, Cretaceous, British Columbia: Clapp, 193.
 Cedar Grove (Upper) sandstone, Pennsylvanian, West Virginia: Hennen, 451.
 Cedarville dolomite, Silurian, Ohio: Foerste, 350.
 Cedarville sandstone, Pennsylvanian, West Virginia: Hennen, 451.
 Chagrin shale, Devonian, Ohio: Rogers, 875.
 Chagrin shales, Devonian, Ohio: Verwiebe, 1067.
 Chainman shale, Mississippian, Nevada: Spencer, 975.
 Chanute shale, Pennsylvanian, Missouri: Hinds and Greene, 471.
 Chattahoochee formation, Oligocene, Florida: Sellards, 919.
 Chattahoochee formation, Tertiary, Georgia: Shearer, 936.
 Chattanooga shale, Mississippian, Tennessee: Dunbar, 306.
 Chazy limestone, Ordovician, Vermont: Perkins, 794.
 Cherokee shale, Pennsylvanian, Missouri: Hinds and Greene, 471.
 Cherryvale shale, Pennsylvanian, Missouri: Hinds and Greene, 471.
 Chesapeake group, Tertiary (Miocene), Maryland: Miller *et al.*, 730.
 Cheshire quartzite, Cambrian, Massachusetts: Emerson, 321.
 Chester amphibolite, Ordovician, Massachusetts: Emerson, 321.
 Chester group, Mississippian, Illinois: St. Clair, 886.
 Chico, Cretaceous, California: Clark, 197.
 Chico formation, Cretaceous, California: Waring, 1088.
 Chicopee shale, Triassic, Massachusetts: Emerson, 321.
 Chinle formation, Triassic, Arizona, Utah, and New Mexico: Gregory, 402.
 Choctawhatchee formation, Miocene, Florida: Sellards, 919.
 Chugwater formation, Permo-Carboniferous, Wyoming: Knight, 589.
 Chugwater formation, Triassic, Wyoming: Hewett and Lupton, 461.
 Chuska sandstone, Tertiary, New Mexico and Arizona: Gregory, 402.
 Citronelle formation, Pliocene, Alabama: Hopkins, 488.

- Citronelle formation, Pliocene, Louisiana: Matson, 695.
- Claggett formation, Cretaceous, Montana: Thom, 1020.
- Claggett shale, Cretaceous, Montana: Collier, 223; Hares, 424.
- Clalborne beds, Tertiary, Georgia: Shearer, 936.
- Clalborne group, Eocene, Alabama: Hopkins, 488.
- Clalborne group, Eocene, Louisiana: Matson, 695.
- Clallam formation, Oligocene, Washington: Clarke, 204.
- Clarion member, Pennsylvanian, Ohio: Stout, 1008.
- Clarksburg limestone, Pennsylvanian, West Virginia: Hennen, 451.
- Clear Fork beds, Permian, Texas: Wrather, 1174.
- Clearwater formation, Cretaceous, Alberta: McLearn, 676.
- Cleveland shale, Devonian, Ohio: Rogers, 875.
- Cleveland shales, Devonian, Ohio: Verwiebe, 1067.
- "Clinton" formation, Silurian, Ohio: Rogers, 875.
- Clore formation, Mississippian, Illinois: St. Clair, 886.
- Clore substage, Mississippian, Kentucky: Miller, 727.
- Cloverly formation, Cretaceous, Wyoming: Ziegler, 1189, 1190.
- Cloverly formation, Cretaceous (?), Wyoming: Hewitt and Lupton, 461.
- Coalburg sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Coalburg (Lower) sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Cobalt series, pre-Cambrian, Ontario: Collins, 224; Quirk, 827.
- Cockeysville marble, Cambrian (?), Maryland: Miller *et al.*, 730.
- Cody formation, Cretaceous, Wyoming: Ziegler, 1189.
- Cody shale, Cretaceous, Wyoming: Ziegler, 1190.
- Cody shale, Cretaceous (?), Wyoming, Hewitt and Lupton, 461.
- Coeymans limestone, Devonian, Pennsylvania: Reeside, 841.
- Coldwater shale, Mississippian, Michigan: Sherzer, 917.
- Coles Brook limestone, Archean, Massachusetts: Emerson, 321.
- Collier shale, Cambrian, Arkansas: Miser, 737.
- Collingwood formation, Ordovician, Ontario: Raymond, 833.
- Colorado group, Cretaceous, Alberta: Downing, 296.
- Colorado group, Cretaceous, Montana: Collier, 223.
- Colorado shale, Cretaceous, Montana: Hares, 424; Stebinger, 984.
- Colorado shale, Cretaceous, New Mexico: Darton, 257.
- Colquitz gneiss, Jurassic, British Columbia: Clapp, 193.
- Columbia formation, Quaternary, New Jersey: Salisbury and Knapp, 890.
- Columbia group, Quaternary (Pleistocene), Maryland: Miller *et al.*, 730.
- Columbia substage, Quaternary, Kentucky: Miller, 727.
- Columbus limestone, Devonian, Ohio: Rogers, 875.
- Columbus substage, Devonian, Kentucky: Miller, 727.
- Colwood sands and gravels, Pleistocene, British Columbia: Clapp, 193.
- Comanche series, Cretaceous, Texas: Matson and Hopkins, 697.
- Comanche series, Lower Cretaceous, Louisiana: Matson and Hopkins, 696.
- Comanchean system, Wyoming: Ziegler, 1189.
- Comanche Peak, Cretaceous, Texas: Wrather, 1174.
- Conemaugh formation, Pennsylvanian, Ohio: Stout, 1008.
- Conemaugh series, Pennsylvanian, West Virginia: Hennen, 451.
- Conewango formation, Devonian, Pennsylvania: Verwiebe, 1067.
- Connellsville sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Conway schist, Silurian (?), Massachusetts: Emerson, 321.
- Conway schist, Triassic, Massachusetts: Emerson, 321.
- Coon Creek horizon, Cretaceous, Tennessee: Wade, 1072.
- Corbin substage, Pennsylvanian, Kentucky: Miller, 727.
- Corry sandstone, Mississippian, Pennsylvania: Verwiebe, 1066.
- Corryville substage, Ordovician, Kentucky: Miller, 727.
- Coys Hill granite, Carboniferous (or later), Massachusetts: Emerson, 321.
- Crab Orchard clay shale, Silurian, Ohio: Foerste, 350.
- Creston formation, pre-Cambrian, British Columbia: Drysdale, 303.
- Crowsnest volcanics, Cretaceous, British Columbia: Rose, 880.
- Crystal Mountain sandstone, Ordovician (?), Arkansas: Miser, 737.
- Curdsville formation, Ordovician, Kentucky: Raymond, 833.
- Curdsville substage, Ordovician, Kentucky: Miller, 727.
- Curlew substage, Pennsylvanian, Kentucky: Miller, 727.
- Cushing granodiorite, Carboniferous (?), Maine: Katz, 546.
- Cussewago sandstone, Mississippian, Pennsylvania: Verwiebe, 1066.
- Cussewago shale, Mississippian, Pennsylvania: Verwiebe, 1066.

- Cuyahoga formation, Mississippian, Ohio: Stout, 1008.
- Cuyahoga stage, Mississippian, Kentucky: Miller, 727.
- Cynthiana formation, Ordovician, Kentucky: Raymond, 833.
- Cynthiana stage, Ordovician, Kentucky: Miller, 727.
- Cypress formation, Mississippian, Illinois: St. Clair, 886.
- Cypress substage, Mississippian, Kentucky: Miller, 727.
- Cypress Creek chert, Devonian, Tennessee: Dunbar, 306.
- Dakota group, Cretaceous, Alberta: Dowing, 296.
- Dakota sandstone, Cretaceous, New Mexico, Arizona, and Utah: Gregory, 402.
- Dakota sandstone, Cretaceous, North Dakota: Leonard, 633.
- Dalton formation, Cambrian, Massachusetts: Emerson, 321.
- Dana diorite, Carboniferous (or later), Massachusetts: Emerson, 321.
- Davis shale, Cambrian, Missouri: Buehler, 137.
- Dayton limestone, Silurian, Ohio: Foerste, 350.
- Decatur limestone, Devonian, Tennessee: Dunbar, 306.
- De Chelly sandstone, Carboniferous (Permian?), Arizona: Gregory, 402.
- Decorah shale, Ordovician, Minnesota: Raymond, 833.
- Decota sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- De Courcy formation, Cretaceous, British Columbia: Clapp, 193.
- Dedham granodiorite, Devonian (?), Massachusetts: Emerson, 321.
- Deerfield sheet, Triassic (or later), Massachusetts: Emerson, 321.
- Defiance moraine, Quaternary, Michigan: Sherzer, 917.
- Delaware formation, Permo-Carboniferous, Texas: Porch, 811.
- Delaware limestone, Devonian, Ohio: Rogers, 875.
- Delaware substage, Devonian, Kentucky: Miller, 727.
- Derby formation, Cambrian, Missouri: Buehler, 137.
- Detroit interlobate moraine, Quaternary, Michigan: Sherzer, 917.
- Detroit River dolomite, Silurian, Michigan: Sherzer, 917.
- Detroit River series, Silurian, Michigan: Smith, 967.
- Dewey limestone, Pennsylvanian, Oklahoma: Fath, 333.
- Diamond Island slate, Carboniferous, Maine: Katz, 546.
- Dighton conglomerate, Carboniferous, Massachusetts: Emerson, 321.
- Doe Run formation, Cambrian, Missouri: Buehler, 137.
- Dorchester slate member, Carboniferous, Massachusetts: Emerson, 321.
- Double Mountain beds, Permian, Texas: Wrather, 1174.
- Douglas formation, Pennsylvanian, Missouri and Kansas: Hinds and Greene, 471.
- Drum limestone, Pennsylvanian, Missouri: Hinds and Greene, 471.
- Dry Creek shale, Cambrian, Montana: Walcott, 1079.
- Duluth gabbro, pre-Cambrian, Minnesota: Broderick, 119.
- Duncan formation, Cretaceous, British Columbia: Clapp, 193.
- Dundee limestone, Devonian, Michigan: Sherzer, 917.
- Dundee (Onondaga) limestone, Devonian, Michigan: Smith, 967.
- Dunderberg formation, Cambrian, Nevada: Walcott, 1078.
- Dunkard series, Permo-Carboniferous, West Virginia: Hennen, 451.
- Durbin formation, Silurian, Ohio: Foerste, 350.
- Eagle limestone and shale, Pennsylvanian, West Virginia: Hennen, 451.
- Eagle sandstone, Cretaceous, Montana: Collier, 223; Hares, 424; Thom, 1020.
- Eagle sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Eagle Ford shale, Cretaceous, Texas: Hopkins, 486; Matson and Hopkins, 697.
- Eagle Ford shales, Cretaceous, Texas: Udden and Bybee, 1050.
- Eagle Gulch latite, Colorado: Patton, 787.
- East Lynn sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- East Lynn (Upper) sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Eden shale, Ordovician, Kentucky: Shaw, 932.
- Eldorado formation, Cambrian, Nevada: Walcott, 1078.
- Elgin sandstone, Pennsylvanian, Oklahoma: Fath, 333.
- Elliot slate, Carboniferous, Maine and New Hampshire: Katz, 546.
- Elk Basin sandstone member of Eagle sandstone, Cretaceous, Wyoming: Hares, 424.
- Elk Lick limestone, Pennsylvanian, West Virginia: Hennen, 451.
- Ellis formation, Jurassic, Montana: Collier, 223; Pardee, 780.
- El Paso limestone, Ordovician, New Mexico: Darton, 257, 258.
- Ely greenstone, pre-Cambrian, Minnesota: Broderick, 119.
- Ely greenstones, pre-Cambrian, Ontario: Parsons, 784.
- Ely limestone, Pennsylvanian, Nevada: Spencer, 975.
- Embar formation, Carboniferous, Wyoming: Hewett and Lupton, 401.
- Emmet moraine, Quaternary, Michigan: Sherzer, 917.

- Engadine dolomite, Silurian, Michigan: Smith, 967.
- Erving hornblende schist, Carboniferous, Massachusetts: Emerson, 321.
- Espanola gravel, pre-Cambrian, Ontario: Quirk, 827.
- Espanola greywacke, pre-Cambrian, Ontario: Quirk, 827.
- Espanola limestone, pre-Cambrian, Ontario: Quirk, 827.
- Estill substage, Silurian, Kentucky: Miller, 727.
- Etchegoin formation, Pliocene, California: Gester, 372; Nomland, 757, 759.
- Etchegoin group, Pliocene, California: Nomland, 758.
- Euphemia dolomite, Silurian, Ohio: Foerste, 350.
- Eureka quartzite, Ordovician, Nevada: Spencer, 975; Tomlinson, 1027.
- Eutaw formation, Cretaceous, Alabama and Tennessee: Berry, 67.
- Eutaw formation, Cretaceous, Georgia: Shearer, 936.
- Eutaw formation, Cretaceous, Kentucky: Wade, 1073.
- Eutaw formation, Cretaceous, Mississippi: Stephenson, 989.
- Ewing limestone, Pennsylvanian, West Virginia: Hennen, 451.
- Exeter diorite, post-Carboniferous, New Hampshire: Katz, 546.
- Extension formation, Cretaceous, British Columbia: Clapp, 193.
- Fairhaven member, Tertiary (Miocene), Maryland: Miller *et al.*, 730.
- Fairmount substage, Ordovician, Kentucky: Miller, 727.
- Fairview shale, Ordovician, Colorado: Crawford and Worcester, 238.
- Falkirk dolomite, Silurian, New York: Chadwick, 183.
- Falmouth pegmatite, Maine: Katz, 546.
- Farley limestone bed, Pennsylvanian, Kansas and Missouri: Hinds and Greene, 471.
- Farnham formation, Ordovician, Quebec: Knox, 596.
- Fayette sandstone, Eocene, Louisiana: Matson, 695.
- Fernie formation, Jurassic, British Columbia: Rose, 880.
- Fiborn limestone, Silurian, Michigan: Smith, 967.
- Fish Haven dolomite, Ordovician, Utah: Tomlinson, 1027.
- Fish Haven (Lower) dolomite, Ordovician, Utah: Tomlinson, 1027.
- Fitchburg granite, Carboniferous, Massachusetts: Emerson, 321.
- Fitzwilliam granite, Carboniferous (or later), Massachusetts and New Hampshire: Emerson, 321.
- Flanagan formation, Ordovician, Kentucky: Raymond, 833.
- Flanagan limestone, Ordovician, Kentucky: Phalen, 799.
- Flathead quartzite, Cambrian, Montana: Pardee, 780.
- Flathead (?) sandstone, Cambrian, Montana: Walcott, 1079.
- Flaxville formation, Tertiary, Montana: Collier, 222.
- Foremost beds, Cretaceous, Alberta: Dowling, 296.
- Fort Mountain formation, Cambrian, Alberta: Walcott, 1078.
- Fort Union formation, Eocene, North Dakota: Leonard, 633.
- Fort Union formation, Tertiary, Montana: Woolsey *et al.*, 1173.
- Fort Union formation, Tertiary, Wyoming: Ziegler, 1190.
- Fort Union formation, Tertiary (?), Wyoming: Hewett and Lupton, 461.
- Fort Union formation, Wyoming: Wegmann, 1109.
- Fox Hills sandstone, Cretaceous, North Dakota: Leonard, 633.
- Franciscan formation, California: Smith, 962.
- Franciscan group, California: Clark, 191.
- Franklin limestone, pre-Cambrian, Pennsylvania: Jonas, 537.
- Fredonia substage, Mississippian, Kentucky: Miller, 727.
- Freeport (Lower), Pennsylvanian, Ohio: Stout, 1008.
- Freeport (Lower) limestone, Pennsylvanian, West Virginia: Hennen, 451.
- Freeport (Lower) sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Freeport (Upper) limestone, Pennsylvanian, West Virginia: Hennen, 451.
- Freeport (Upper) sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Frontier formation, Cretaceous, Wyoming: Hares, 424; Knowlton, 595; Ziegler, 1189.
- Frontier formation, Cretaceous (?), Wyoming: Hewett and Lupton, 461.
- Frontier sandstones, Cretaceous, Wyoming: Ziegler, 1190.
- Fulton shale, Ordovician, Ohio: Raymond, 833.
- Fulton (Utica) substage, Ordovician, Kentucky: Miller, 727.
- Fusselman limestone, Silurian, New Mexico: Darton, 257, 258.
- Gabriola formation, Cretaceous, British Columbia: Clapp, 193.
- Gallatin formation, Cambrian, Wyoming: Tomlinson, 1027.
- Ganges formation, Cretaceous, British Columbia: Clapp, 193.
- Garrard (Paint Lick) substage, Ordovician, Kentucky: Miller, 727.
- Gaspar (Tribune) substage, Mississippian, Kentucky: Miller, 727.
- Gebo member, Cretaceous, Wyoming: Ziegler, 1189.
- Gebo sandstone, Cretaceous, Wyoming: Ziegler, 1190.

- Gilboy sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Girard shale, Devonian, Pennsylvania: Verwiebe, 1067.
- Glassboro phase, Quaternary, New Jersey: Salisbury and Knapp, 890.
- Glen Dean (Sloans Valley) substage, Mississippian, Kentucky: Miller, 727.
- Glendon limestone member, Oligocene, Alabama: Hopkins, 488.
- Glen Rose limestone, Texas: Shuler, 944.
- Glens Falls formation, Ordovician, New York: Raymond, 833.
- Gloucester formation, Ordovician, Ontario: Raymond, 833.
- Golconda formation, Mississippian, Illinois: St. Clair, 886.
- Golconda substage, Mississippian, Kentucky: Miller, 727.
- Gonic formation, Carboniferous, Maine and New Hampshire: Katz, 546.
- Goodridge formation, Pennsylvanian, Utah: Gregory, 402.
- Gordon formation, Cambrian, Montana: Walcott, 1079.
- Gordon shale, Cambrian, Montana: Walcott, 1078.
- Goshen schist, Ordovician (?), Virginia, North Carolina: Laney, 608.
- Goshen schist, Silurian (?), Massachusetts: Emerson, 321.
- Gosport sand, Eocene, Alabama: Hopkins, 488.
- Gowganda formation, pre-Cambrian, Ontario: Collins, 224; Quirke, 827.
- Grafton sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Granby tuff, Triassic, Massachusetts: Emerson, 321.
- Grand Falls chert, Mississippian, Missouri: Buehler, 137.
- Grand Rapids formation, Cretaceous, Alberta: McLearn, 676.
- Greendale substage, Ordovician, Kentucky: Miller, 727.
- Greer formation, Permian, Texas: Wrather, 1174.
- Grenville formation, pre-Cambrian, Quebec: Dresser, 298.
- Grenville series, pre-Cambrian, New York: Cushing, 245; Miller, 733; Newland, 753.
- Grenville series, pre-Cambrian, Quebec: Wilson, 1153, 1154.
- Greylock schist, Ordovician, Massachusetts: Emerson, 321.
- Grosse Isle moraine, Quaternary, Michigan: Sherzer, 917.
- Gulf series, Cretaceous, Texas: Matson and Hopkins, 697.
- Gulf series (Upper Cretaceous), Louisiana: Matson and Hopkins, 696.
- Gunflint formation, pre-Cambrian, Minnesota: Broderick, 119.
- Gym limestone, Carboniferous, New Mexico: Darton, 257.
- Hall series, Triassic (?), British Columbia: Drysdale, 302.
- Hampden diabase, Triassic (or later), Massachusetts: Emerson, 321.
- Hardinsburg formation, Mississippian, Illinois: St. Clair, 886.
- Hardinsburg substage, Mississippian, Kentucky: Miller, 727.
- Hardwick granite, Carboniferous (or later), Massachusetts: Emerson, 321.
- Hardyston quartzite, Cambrian, Pennsylvania: Miller, 728.
- Harrodsburg substage, Mississippian, Kentucky: Miller, 727.
- Haslam formation, Cretaceous, British Columbia: Clapp, 193.
- Hasmark formation, Cambrian, Montana: Pardee, 780.
- Hatchetigbee formation, Eocene, Alabama: Hopkins, 488.
- Hattiesburg clay, Oligocene, Louisiana: Matson, 695.
- Hawley schist, Ordovician, Massachusetts: Emerson, 321.
- Haydens Peak latite, Colorado: Patton, 787.
- Hazleton group, Jurassic and Triassic, British Columbia: Dolmage, 292.
- Hecla sandstone, Pennsylvanian, Ohio: Stout, 1008.
- Helderberg limestone, Devonian, Pennsylvania: Reeside, 841.
- Hendricks series, Silurian, Michigan: Smith, 967.
- Henley member, Mississippian, Ohio: Stout, 1008.
- Henrietta formation, Pennsylvanian, Missouri: Hinds and Greene, 471.
- Hermitage formation, Ordovician, Kentucky: Raymond, 833.
- Hermitage formation, Ordovician, Tennessee: Raymond, 833.
- Hermitage substage, Ordovician, Kentucky: Miller, 727.
- Heuvelton sandstone, Cambrian (Ozarkian), New York: Cushing, 245.
- Highbridge limestone, Ordovician, Kentucky: Shaw, 932.
- Highbridge stage, Ordovician, Kentucky: Miller, 727.
- Hinsdale gneiss, Archean, Massachusetts: Emerson, 321.
- Holtsclaw substage, Mississippian, Kentucky: Miller, 727.
- Holyoke diabase, Triassic (or later), Massachusetts: Emerson, 321.
- Homewood sandstone, Pennsylvanian, Ohio: Stout, 1008.
- Homewood sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Homewood substage, Pennsylvanian, Kentucky: Miller, 727.
- Hoopln slate, Cambrian, Massachusetts: Emerson, 321.
- Hoosac schist, Ordovician, Massachusetts: Emerson, 321.
- Horsethief sandstone, Cretaceous, Montana: Stebbins, 984.

- Hubbardston granite, Carboniferous, Massachusetts: Emerson, 821.
- Hull formation, Ordovician, Ontario: Raymond, 833.
- Huron shale, Devonian, Ohio: Rogers, 875.
- Huron shales, Devonian, Ohio: Verwiebe, 1087.
- Hyco quartz porphyry, Ordovician (?), Virginia, North Carolina: Laney, 608.
- Iatan limestone member, Pennsylvanian, Missouri and Kansas: Hinds and Greene, 471.
- Iatan (Kickapoo) limestone, Pennsylvanian, Kansas: Twenhofel, 1044.
- Idaho beds, Pliocene, Idaho: Merriam, 713.
- Idaho Springs formation, pre-Cambrian, Colorado: Bastin and Hill, 53.
- Ilo formation, Cretaceous, Wyoming: Ziegler, 1190.
- Indian Fields stage, Silurian, Kentucky: Miller, 727.
- Iola limestone, Pennsylvanian, Missouri: Hinds and Greene, 471.
- Iowan drift, Pleistocene, Iowa: Alden and Leighton, 10.
- Irasburg conglomerate, Ordovician, Vermont: Richardson, 853.
- Irene conglomerate, Cambrian, British Columbia: Drysdale, 308.
- Iron formation, pre-Cambrian, Ontario: Parsons, 784.
- Jackfork sandstone, Carboniferous, Arkansas: Miser, 737.
- Jackson formation, Eocene, Alabama: Hopkins, 488.
- Jackson formation, Eocene, Louisiana: Matson, 695.
- Jacksonburg limestone, Ordovician, Pennsylvania: Miller, 728.
- Jane Lew sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Jefferson dolomite, Devonian, Montana, Utah, and Wyoming: Tomlinson, 1027.
- Jefferson limestone, Devonian, Montana: Pardee, 780.
- Jefferson City dolomite, Ordovician, Missouri: Buehler, 137.
- Jeffersonville substage, Devonian, Kentucky: Miller, 727.
- Jelm formation, Triassic, Wyoming: Knight, 589.
- Jewell phyllite, Carboniferous, Maine: Katz, 546.
- Joana limestone, Mississippian, Nevada: Spencer, 975.
- Judith River formation, Cretaceous, Montana: Collier, 223; Hares, 424; Thom, 1020.
- Kalbab limestone, Pennsylvanian, Arizona, Utah: Gregory, 402.
- Kanawha black flint, Pennsylvanian, West Virginia: Hennen, 451.
- Kanawha group, Pennsylvanian, West Virginia: Hennen, 451.
- Kansas City formation, Pennsylvanian, Missouri: Hinds and Greene, 471.
- Kaskaskia (Chester) series, Mississippian, Kentucky: Miller, 727.
- Kenwood substage, Mississippian, Kentucky: Miller, 727.
- Keokuk limestone, Mississippian, Illinois: Hinds, 469, 470.
- Keyser limestone member, Devonian, Pennsylvania: Reeside, 841.
- Kimmswick limestone, Ordovician, Illinois and Missouri: Raymond, 833.
- Kingsdown marls, Quaternary, Kansas: Hay, 434.
- Kittanning sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Kittery quartzite, Carboniferous, Maine and New Hampshire: Katz, 546.
- Knapp formation, Devonian, Pennsylvania: Verwiebe, 1087.
- Knife Lake formation, pre-Cambrian, Ontario: Parsons, 784.
- Knife Lake slates, pre-Cambrian, Minnesota: Broderick, 119.
- Knoxville formation, Cretaceous, California: Clark, 197.
- Kona dolomite, Algonkian, Michigan: Smith, 967.
- Kootenai formation, Cretaceous, Montana: Pardee, 780; Stebinger, 984.
- Kootenai (?) formation, Cretaceous, Montana: Collier, 223.
- Kootenay formation, Cretaceous, British Columbia: Rose, 880.
- La Biche formation, Cretaceous, Alberta: McLearn, 676.
- Lafayette substage, Pliocene, Kentucky: Miller, 727.
- LaGrange substage, Eocene, Kentucky: Miller, 727.
- Lake Louisa shale, Cambrian, Alberta: Walcott, 1078.
- Laketown dolomite, Silurian and Devonian, Utah: Tomlinson, 1027.
- Lake Trammel sandstone, Permian, Texas: Wrather, 1174.
- Lake Valley limestone, Mississippian, New Mexico: Darton, 257, 258.
- LaMotte sandstone, Cambrian, Missouri: Buehler, 137.
- Lance formation, Tertiary (?), Montana: Woolsey *et al.*, 1173.
- Lance formation, Tertiary (?), North Dakota: Leonard, 633.
- Lance formation, Tertiary (?), Wyoming: Hewett and Lupton, 461.
- Lance formation, Wyoming: Wegemann, 1109.
- Lane shale, Pennsylvanian, Kansas and Missouri: Hinds and Greene, 471.
- Lansing formation, Pennsylvanian, Missouri and Kansas: Hinds and Greene, 471.
- La Plata group, Jurassic, Arizona, Utah, and New Mexico: Gregory, 402.
- Laurel limestone, Silurian, Ohio and Indiana: Foerste, 350.
- Laurel substage, Silurian, Kentucky: Miller, 727.

- Laurentian gneiss, pre-Cambrian, Quebec : Dresser, 298.
- Lawrence shale member, Pennsylvanian, Missouri and Kansas : Hinds and Greene, 471.
- Lawrence shales, Pennsylvanian, Kansas : Twenhofel, 1044.
- Leadville limestone, Devonian-Mississippian, Colorado : Crawford and Worcester, 238.
- Lebo shale member, Tertiary, Montana : Woolsey *et al.*, 1173.
- Lee quartz diorite, Archean, Massachusetts : Emerson, 321.
- Leech River formation, Carboniferous (?), British Columbia : Clapp, 193.
- Leigh formation, Ordovician, Utah : Tomlinson, 1027.
- Leithsville shaly limestone, Cambrian, Pennsylvania : Miller, 728.
- Lennep sandstone, Cretaceous, Montana : Thom, 1020.
- Leona rhyolite, Pliocene (?), California : Clark, 197.
- Le Roy shales, Pennsylvanian, Kansas : Twenhofel, 1044.
- Lewis shale, Cretaceous, Wyoming : Hares, 424.
- Lexington limestone, Ordovician, Kentucky : Shaw, 932.
- Lexington stage, Ordovician, Kentucky : Miller, 727.
- Leyden argillite, Silurian (?), Massachusetts : Emerson, 321.
- Liberty substage, Ordovician, Kentucky : Miller, 727.
- Lilley member, Silurian, Ohio : Foerste, 350.
- Linden shale and limestone, Devonian, Tennessee : Dunbar, 306.
- Lisbon formation, Eocene, Alabama : Hopkins, 488.
- L'Islet formation, Cambrian, Quebec : Knox, 596.
- Lobo formation, Triassic (?), New Mexico : Darton, 257.
- Logan formation, Mississippian, Ohio : Stout, 1008.
- Logan sills, pre-Cambrian, Minnesota : Broderick, 119.
- Long Lake series, Devonian, Michigan : Smith, 967.
- Longmeadow sandstone, Triassic, Massachusetts : Emerson, 321.
- Lorette formation, Ordovician, New York : Raymond, 833.
- Lorrain quartzite, Cambrian, Ontario : Collins, 224.
- Louisville substage, Silurian, Kentucky : Miller, 727.
- Lowville limestone, Ordovician, New York, Coryell, 237.
- Lueders limestone, Permian, Texas : Wrather, 1174.
- Lulbegrud substage, Silurian, Kentucky : Miller, 727.
- McBean formation, Tertiary, Georgia : Shearer, 936.
- McElmo formation, Jurassic (?), New Mexico, Arizona, and Utah : Gregory, 402.
- Mackworth slate, Carboniferous, Maine : Katz, 546.
- McLeansboro formation, Pennsylvanian, Illinois : Cady, 151.
- McMurray formation, Cretaceous, Alberta : McLearn, 676.
- McNairy sand member, Cretaceous, Tennessee : Wade, 1072.
- Madison limestone, Carboniferous, Montana : Collier, 223.
- Madison limestone, Carboniferous, Wyoming : Hewett and Lupton, 461.
- Madison limestone, Mississippian, Montana : Pardee, 780.
- Madison limestone, Mississippian, Montana and Utah : Tomlinson, 1027.
- Magothy formation, Cretaceous, Maryland : Miller *et al.*, 730.
- Mahoning sandstone, Pennsylvania, Ohio : Stout, 1008.
- Mahoning (Middle) sandstone, Pennsylvanian, West Virginia : Hennen, 451.
- Mahoning (Lower) sandstone, Pennsylvanian, West Virginia : Hennen, 451.
- Mahoning (Upper) sandstone, Pennsylvanian, West Virginia : Hennen, 451.
- Malahat volcanics, Carboniferous (?), British Columbia : Clapp, 193.
- Mammoth Cave series, Mississippian, Kentucky : Miller, 727.
- Mancos shale, Cretaceous, New Mexico, Arizona, and Utah : Gregory, 402.
- Manigotagan granite, pre-Cambrian, Manitoba : Dresser, 299.
- Manistique series, Silurian, Michigan : Smith, 967.
- Mannington sandstone, Permo-Carboniferous, West Virginia : Hennen, 451.
- Marianna limestone, Oligocene, Alabama : Hopkins, 488.
- Marianna limestone, Tertiary, Florida : Cooke, 232.
- Mariposa formation, Jurassic, California : Moody, 742.
- Marlboro formation, Algonkian (?), Massachusetts and Rhode Island : Emerson, 321.
- Martinez formation, Tertiary, California : Waring, 1088.
- Martinsburg shale, Ordovician, Pennsylvania : Raymond, 833.
- Martinsburg shale, Ordovician, Pennsylvania : Miller, 728.
- Matawan formation, Cretaceous, Maryland : Miller *et al.*, 730.
- Mattapan volcanic complex, Carboniferous, Massachusetts : Emerson, 321.
- Maxfield formation, Cambrian, Utah : Tomlinson, 1027.
- Maxville limestone, Mississippian, Ohio : Stout, 1008.

- Maxville(?) limestone, Mississippian, Kentucky: Shaw, 932.
- Mayaville formation, Ordovician, Kentucky: Shaw, 932.
- Maywood formation, Silurian(?), Montana: Pardee, 780.
- Mazarn shale, Ordovician, Arkansas: Miser, 737.
- Meade gravels, Quaternary, Kansas: Hay, 434.
- Meadville formation, Mississippian, Pennsylvania: Verwiebe, 1066.
- Meagher limestone, Cambrian, Montana: Walcott, 1079.
- "Medina" shale, Silurian, Ohio: Rogers, 875.
- Meeteetse formation, Cretaceous, Wyoming: Hewett and Lupton, 461; Ziegler, 1190.
- Meeteetse member, Cretaceous, Wyoming: Ziegler, 1189.
- Menard formation, Mississippian, Illinois: St. Clair, 886.
- Menard substage, Mississippian, Kentucky: Miller, 727.
- Mercer (Lower) limestone, Pennsylvanian, Ohio: Stout, 1008.
- Mercer (Upper) limestone, Pennsylvanian, Ohio: Stout, 1008.
- Merkel dolomite, Permian, Texas: Wrather, 1174.
- Merrimack quartzite, Carboniferous, Massachusetts: Emerson, 321.
- Mesaverde formation, Cretaceous, New Mexico and Arizona: Gregory, 402.
- Mesaverde formation, Cretaceous, Wyoming: Hares, 424; Ziegler, 1189, 1190.
- Mesaverde formation, Cretaceous (?), Wyoming: Hewett and Lupton, 461.
- Metcosin volcanics, Eocene, British Columbia: Clapp, 193.
- Middlefield granite, Carboniferous (or later), Massachusetts: Emerson, 321.
- Midway formation, Eocene, Louisiana: Matson, 695.
- Midway formation, Eocene, Louisiana: Matson and Hopkins, 696.
- Midway formation, Tertiary, Georgia: Shearer, 936.
- Midway formation, Tertiary, Texas: Matson and Hopkins, 697.
- Midway formation, Tertiary (Eocene), Texas: Hopkins, 486.
- Millford granite, Devonian (?), Massachusetts: Emerson, 321.
- Milk River sandstone, Cretaceous, Alberta: Dowling, 296.
- Million substage, Ordovician, Kentucky: Miller, 727.
- Mississagi quartzite, pre-Cambrian, Ontario: Quirke, 827.
- Missouri Mountain slate, Silurian, Arkansas: Miser, 737.
- Moccasin limestone, Ordovician, Virginia: Raymond, 833.
- Moenkopi formation, Carboniferous (Permian?), Arizona and Utah: Gregory, 402.
- Monmouth formation, Cretaceous, Maryland: Miller *et al.*, 730.
- Monongahela series, Pennsylvanian, West Virginia: Hennen, 451.
- Monroe formation, Silurian, Ohio: Rogers, 875.
- Monroe group, Silurian, Michigan: Sherzer, 917.
- Monroe (Lower) series, Silurian, Michigan: Smith, 967.
- Monson granodiorite, Carboniferous (or later), Massachusetts: Emerson, 321.
- Montana group, Cretaceous, Montana: Stebinger, 984.
- Monterey formation, Miocene, California: Smith, 962.
- Monterey shale, Cretaceous, California: Hawley, 431.
- Montoya limestone, Ordovician, New Mexico: Darton, 257, 258.
- Mooreville tongue of Selma chalk, Cretaceous, Mississippi: Stephenson, 989.
- Morgantown sandstone, Pennsylvanian, West Virginia: Hennen, 451.
- Morrison formation, Cretaceous: Schuchert, 912.
- Morrison formation, Cretaceous, Colorado: Lee, 625.
- Morrison formation, Cretaceous, Wyoming: Ziegler, 1189, 1190.
- Morrison formation, Cretaceous(?), Wyoming: Hewett and Lupton, 461.
- Morse Creek limestone, Devonian, New York: Grabau, 393.
- Mount Auburn substage, Ordovician, Kentucky: Miller, 727.
- Mount Clemens moraine, Quaternary, Michigan: Sherzer, 917.
- Mount Hope substage, Ordovician, Kentucky: Miller, 727.
- Mount Roberts formation, Carboniferous, British Columbia: Bruce, 132.
- Mount Selman formation, Tertiary (Eocene), Texas: Hopkins, 486.
- Mount Toby conglomerate, Triassic, Massachusetts: Emerson, 321.
- Mount Whyte formation, Cambrian, British Columbia: Walcott, 1079.
- Mount Whyte formation, Cambrian, British Columbia and Alberta: Walcott, 1080.
- Mowry formation, Cretaceous, Wyoming: Ziegler, 1189.
- Mowry shale, Cretaceous, Montana: Collier, 223.
- Mowry shale, Cretaceous, Wyoming: Hares, 424; Ziegler, 1190.
- Mowry shale, Cretaceous(?), Wyoming: Hewett and Lupton, 461.
- Murfreesboro stage, Miocene, Virginia and North Carolina: Olsson, 764.
- Nacatoch sand, Cretaceous, Louisiana: Matson and Hopkins, 696.
- Nanaimo series, Cretaceous, British Columbia: Clapp, 193.
- Navajo sandstone, Jurassic, New Mexico, Arizona, Utah: Gregory, 402.

- Navarro formation, Cretaceous, Texas: Hopkins, 486; Matson and Hopkins, 697.
- Nazareth cement limestone, Ordovician, Pennsylvania: Miller, 728.
- Nelson granodiorite, Jurassic, British Columbia: Bruce, 132.
- Nenana gravel, Tertiary (?), Alaska: Capps, 174.
- Nevada limestone, Devonian, Nevada: Spencer, 975.
- Newark group, Triassic, Massachusetts: Emerson, 321.
- Newark sandstone, Triassic, Virginia: Laney, 608.
- Newbury volcanic complex, Silurian or Devonian, Massachusetts: Emerson, 321.
- Newburyport quartz diorite, Devonian (?), Massachusetts: Emerson, 321.
- Newington moraine, Pleistocene, Maine, New Hampshire, and Massachusetts: Kats and Keith, 547.
- Newman series, Mississippian, Kentucky: Miller, 727.
- New Providence substage, Mississippian, Kentucky: Miller, 727.
- New Salem aplite, Carboniferous (or later), Massachusetts: Emerson, 321.
- New Scotland limestone, Devonian, Pennsylvania: Reeside, 841.
- Niagara limestone, Silurian, Michigan: Smith, 967.
- Niagara limestone, Silurian, Ohio: Rogers, 875.
- Niobrara formation, Cretaceous, North Dakota: Leonard, 633.
- Niobrara shale, Cretaceous, Wyoming: Hares, 424.
- Nisconlith series, pre-Cambrian, British Columbia: Drysdale, 303.
- Normanskill shale, Ordovician, New York: Raymond, 833.
- Northbridge granite gneiss, Archean, Massachusetts: Emerson, 321.
- Northumberland formation, Cretaceous, British Columbia: Clapp, 193.
- Oakland conglomerate, Cretaceous, California: Clark, 197.
- Oakdale quartzite, Carboniferous, Massachusetts: Emerson, 321.
- O-atka beds, Silurian, New York: Chadwick, 183.
- Ocala limestone, Eocene, Florida: Cooke, 232.
- Ocala limestone, Tertiary, Georgia: Shearer, 936.
- Ogden quartzite, Ordovician, Utah: Tomlinson, 1027.
- Ogdensburg formation, Ordovician, New York, Cushing, 245.
- Ogishke conglomerate, pre-Cambrian, Minnesota: Broderick, 119.
- O'Hara substage, Mississippian, Kentucky: Miller, 727.
- Ohio formation, Devonian, Ohio: Stout, 1008.
- Ohio shale, Devonian, Kentucky: Shaw, 932.
- Ohio shale, Devonian, Ohio: Verwiebe, 1067.
- Ohio shale group, Devonian, Ohio: Rogers, 875.
- Ohio substage, Devonian, Kentucky: Miller, 727.
- Oktibbeha tongue of Selma chalk, Cretaceous, Mississippi: Stephenson, 989.
- Oldham substage, Silurian, Kentucky: Miller, 727.
- Olentangy shale, Devonian, Ohio: Grabau 393; Verwiebe, 1067.
- Olentangy (?) shale, Devonian, Ohio: Rogers, 875.
- Olmstead shales, Devonian, Ohio: Verwiebe, 1067.
- Orangeville formation, Mississippian, Pennsylvania: Verwiebe, 1066.
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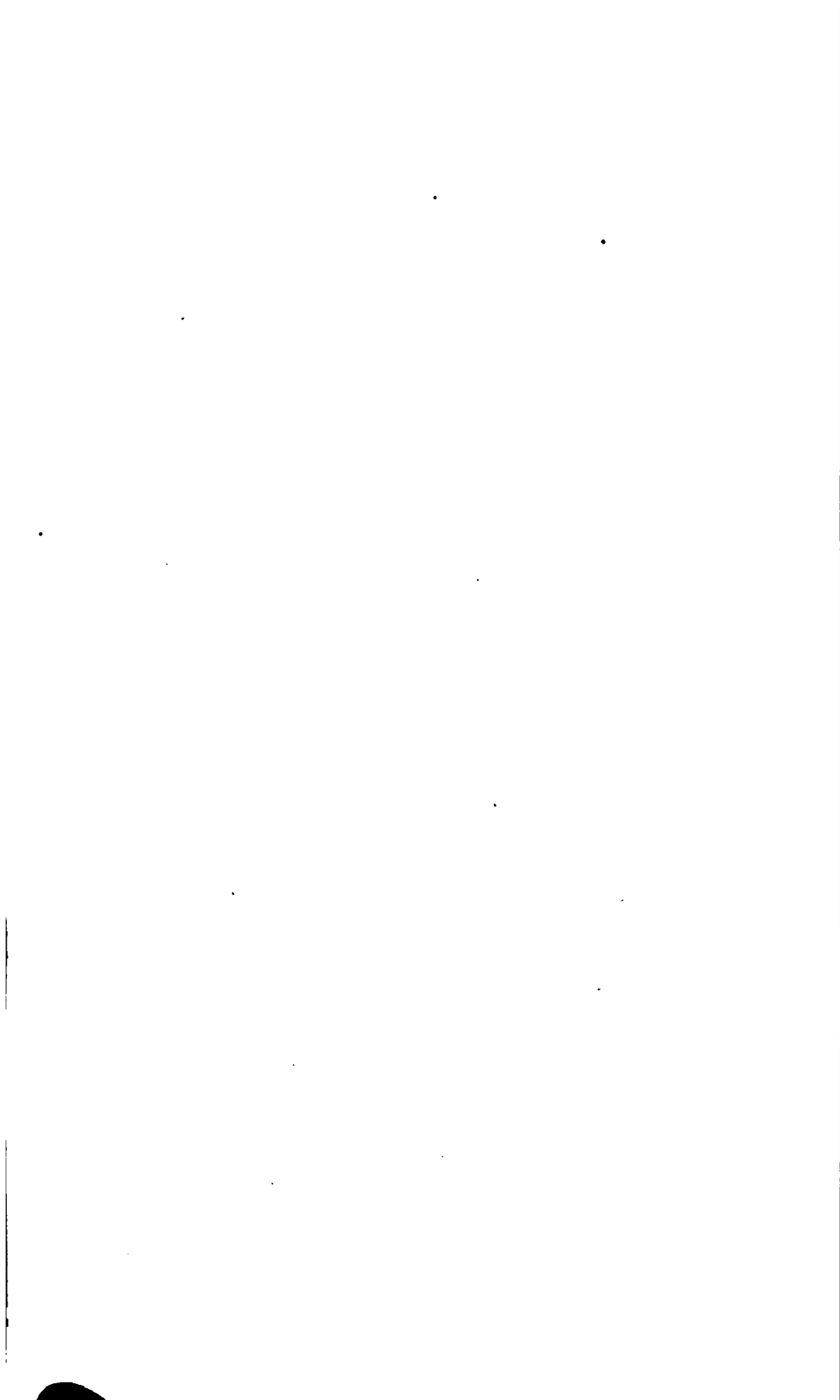
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UNITED STATES GEOLOGICAL SURVEY

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Bulletin 685

RELATION OF LANDSLIDES AND GLACIAL
DEPOSITS TO RESERVOIR SITES

IN THE

SAN JUAN MOUNTAINS, COLORADO

BY

WALLACE W. ATWOOD



WASHINGTON

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1918

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RELATION OF LANDSLIDES AND GLACIAL DEPOSITS TO RESERVOIR SITES IN THE SAN JUAN MOUNTAINS, COLORADO.

By WALLACE W. ATWOOD.

INTRODUCTION.

With the increase in farming on the lowlands bordering the San Juan Mountains, Colo., and on the broader valley floors within the range, there has come a demand for a large supply of water to be used for irrigation. This demand has been particularly urgent on the east side of the range, among the farmers and ranchmen of the San Luis Valley. Numerous reservoirs have been planned in which the waters from the melting snows and the surplus floods from heavy rains may be stored, to be later released as needed during the growing season.

Most of the reservoir projects are associated with the great glaciated canyons of the range or with lake basins in which the waters have been artificially raised. In some of them the selection of the reservoir site has apparently been determined by the occurrence of a narrow gorge or constricted portion in the canyon, downstream from a broad, open, parklike portion. In many of these mountain valleys, however, the narrow portions have been formed by the deposition of large masses of loose material, either of landslide or of glacial origin, and such materials have not proved to be watertight. Most of the lakes in the mountains are also held back by glacial or landslide deposits. In many of the projects a perfectly good watertight dam has been constructed, but serious leakages have occurred, the waters finding a way underneath or around one end, or even both ends, of the dam. For these reasons, some projects appear to have been abandoned, and others are continued with heavy expenses for repairs. On one reservoir large additional construction has been undertaken to prevent disastrous leakage through a glacial moraine and the threatened loss of the entire amount of capital invested. Nevertheless, other reservoirs are being planned in places where just such loose materials border the sites of the proposed dams.

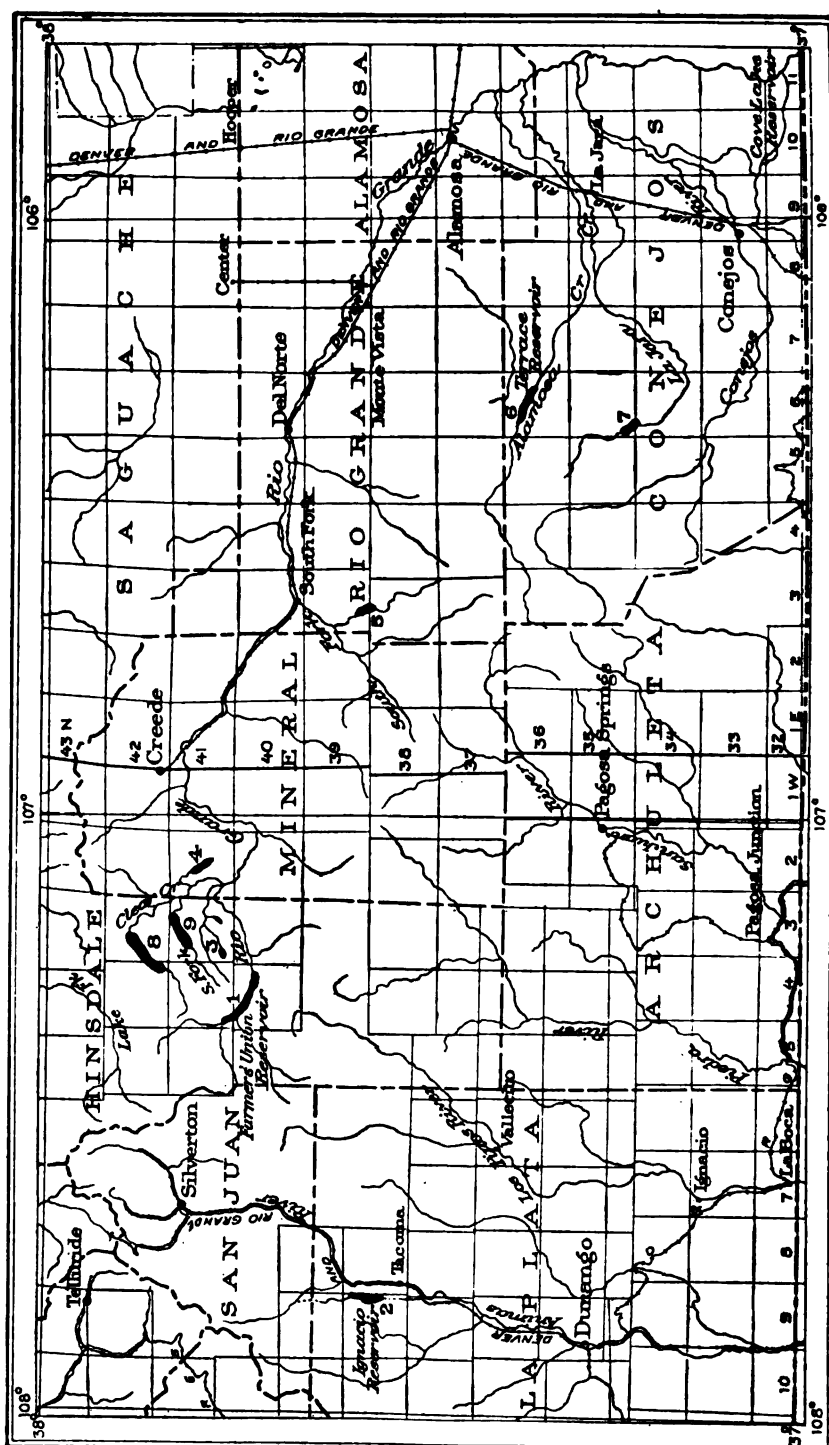


FIGURE 1.—Index map showing location and drainage features of reservoir projects in the San Juan Mountains. 1, Farmers' Union or Rio Grande reservoir; 2, Ignacio reservoir; 3, Road Canyon reservoir; 4, Santa Maria reservoir; 5, Mazon reservoir or Hammer Creek project; 6, Terrace reservoir; 7, La Jara reservoir; 8, proposed reservoir site on Clear Creek; 9, proposed reservoir site on North Fork of Clear Creek. Note about 176 miles to scale.

Inasmuch as experience has shown that many landslide masses and certain of the glacial deposits are not able to withstand the pressure of a high head of water without serious leakage, it seems desirable to publish a description of the mountain canyons and the deposits commonly found in them and of the geologic conditions associated with the lakes in the mountains, so that, in the future, no expensive errors need be due to a failure to recognize the geologic formations bordering a proposed reservoir site.

LOCATION.

The San Juan Mountains are in the southwestern part of Colorado. (See fig. 1.) The loftier summits in the range rise to elevations of over 14,000 feet, and the highest peak, known as Uncompahgre, has an elevation of 14,306 feet. Much of the range is above 10,000 feet in elevation. To the west the bordering lower lands form the Colorado Plateau, whose elevation is between 7,000 and 8,000 feet above the sea. The Uncompahgre Plateau lies at the northwest and ranges in elevation from 9,000 feet near the mountains to 8,000 feet, and at a still greater distance from the mountains, to 7,000 feet above sea level. North of the range, in the vicinity of Montrose, in the great valley of the Uncompahgre River, there is an area at about 5,000 feet, but just east of this area is another plateau district connecting the San Juan Mountains with the West Elk Mountains, and into that plateau the Black Canyon of the Gunnison has been cut. To the east is the broad San Luis Valley, with a general elevation of about 7,500 feet, and on the south the plateau and mesa country of northern New Mexico.

PHYSICAL GEOGRAPHY.

PHYSIOGRAPHIC EVOLUTION OF THE REGION.

The San Juan district has passed through a remarkable geologic history. The earlier chapters of that history need not be reviewed here,¹ but the later chapters, which cover an interpretation of the present topography, should be outlined.

At the end of Cretaceous time the range appeared as a great mountain mass—a huge dome. (See fig. 2.) Rivers went to work upon that uplifted land and carved out the early Tertiary San Juan Mountains. Alpine glaciers were formed in the basins among those mountains and descended to the neighboring lowlands. In time, through the combined efforts of rivers, glaciers, winds, and all agents of weathering, the mountains were removed and the region was re-

¹ The early geologic history of the range is clearly stated in the Telluride, Silverton, Needle Mountains, and Ouray folios of the Geologic Atlas, published by the United States Geological Survey.



Figure 2.—Diagrammatic cross section showing the physiographic evolution of the San Juan region since the beginning of Tertiary time. a, Pre-Cambrian schist and gneiss; b, Algonkian quartzites; c, pre-Cambrian granitic intrusive; d, Paleozoic and Mesozoic rocks; e, Ridgway till and Tertiary volcanic rocks; f, middle and late Tertiary volcanic rocks; g, Tertiary intrusive rocks.

duced to one of low relief, not far above sea level. Before this work was completed volcanoes had broken out in the range, and by the end of the Oligocene epoch vast amount of sand and gravel were spread out over the western part of the area.

Next came a second series of violent and extensive volcanic outbursts. From numerous vents fragmental materials were thrown into the air, and lavas were poured out over the surface. Little by little these formations coming from many centers, built up an extensive volcanic plateau, which, if restored would rise at least a few thousand feet above the highest summits of the present range. By this time the Pliocene or late Tertiary epoch had been reached.

After the development of the great volcanic plateau the streams again undertook their work of dissection. Another range of mountains was carved out, and once more after the rivers had worked for a long time the region was reduced to a lowland not much above sea level. The old surface produced at that time is represented by many of the broad summits and intercanion ridges of the present range.

Still later the San Juan area was again uplifted. This time the erosion surface that had just been produced was domed. The streams were invigorated by the greater elevation of the mountains and began at once to lower their courses. A long period of stream erosion followed, and associated with it were at least three stages of glaciation, during each of which the mountain canyons were occupied by ice. Through the combined efforts of ice and water the major features of the present topography were developed.

Since the melting away of the last glacier there has been a renewed and vigorous attack on the mountains by streams and by all those agents which assist in the weathering or disintegration of rocks. Vast quantities of

loose material have been taken down the canyon walls. The mountain slopes left too steep to stand when the last ice melted have loosened, and great areas of landslides have been formed. The morainic deposits left by the glaciers contain lake basins, and at many places such deposits have partly filled the valleys and even ponded the streams. In the higher mountains there are places where the ice actually gouged basins out of the solid rock, and in such basins waters have accumulated. Mud flows and torrential fans have also ponded certain of the streams and caused lakes to come into existence. Some lakes have been filled and others have been drained. Broad flood plains have been developed, and by the intrenchment of stream courses below former flood plains many terraces have been left. The range is to-day being actively eroded, and great masses are slipping or sliding from the oversteepened mountain slopes. There are reasons for believing that the range is also being slowly uplifted.

GREAT CANYONS.

The great canyons of the San Juan region head in the central part of the mountain area and lead radially to the bordering plateaus. At their heads and at the heads of the several tributaries to these major canyons there are broad, open semicircular areas where the snows collected during the several glacial stages and formed the alpine glaciers. The vigor of ice action, even at the very beginning of movement, is recorded in these ancient catchment basins or cirques by deep gouging into the solid rock and by grooved, polished, and striated surfaces. The bordering wall of a cirque is usually very steep, in places precipitous, for the work underneath the glacier led to a continual enlargement of the catchment area, so that the inter-canyon or intercirque ridges became narrower and narrower, locally even coming to have sharp, jagged, sawtooth forms. During the period of maximum formation of ice the sharp peaks were all that rose above the glaciers and the associated snow fields. The catchment areas as examined to-day range in area from a fraction of a square mile to as much as 15 square miles.

Downstream from the cirques the canyons usually retain an open or U-shaped form, being in sharp contrast to unglaciated canyons, such as the Black Canyon of the Gunnison, at the north margin of the range, and the Toltec gorge, at the southeast, for such stream-eroded canyons are V-shaped. The walls of the great canyons in the range are in places smooth and even polished from ice action. The bold or fantastic rock features which certainly must have existed there before the ice passed through the canyons have been removed, and there is a general simplicity to the canyon walls. On the floors of the canyons it is evident, at many places, that there has been

vigorous ice action. Grooved, polished, and striated surfaces are still preserved, and vast deposits of glacial *débris* are lodged in the lower portions of the valleys.

Many of the tributary canyons terminate several hundred feet above the bottom of the main canyon, so that their waters now tumble or fall into the main gorge. Such hanging valleys were usually occupied by ice, but the deepening work of the tributary glaciers fell far short of that accomplished by the glaciers in the main canyons.

The floors of the glaciated canyons are very irregular and do not have the normal gradients of stream courses, for the work of glacier ice is not controlled by the same laws that control the work of running water. In some places the ice has gouged out holes much below the general gradient; in others rock hills or knobs have been left on the floors of the valleys. The *débris* left by the ice during its advance and upon its final melting has added numerous details in the topography of the canyon floors and the lower slopes, so that many of the postglacial streams in such canyons flow here on gentle gradients through meadow lands, there over rocky places where cataracts and rapids exist, or through some narrow notch cut in a rock ledge or morainic ridge. Some of the lakes in the canyons are due to these irregularities in the stream bed, either in the solid rock or in the glacial *débris*. At many places vast quantities of material have slumped into the canyon from one side or the other, or from both sides, so as to block the course of the stream. At a few places muds have formed and come down the canyon slopes, and opposite the mouth of each small tributary stream there is usually a torrential fan. The recognition of these looser deposits is of special significance in the selection of reservoir sites, and each class is described in detail below.

GLACIAL DEPOSITS IN THE CANYONS.

TERMINAL MORAINES.

While a glacier occupies a mountain canyon there is constant movement of the ice down that canyon. The walls and floor of the canyon are scraped bare of loose material. At the margin of the ice in the position of maximum advance excessive melting is taking place and heavy deposits of glacial drift accumulate. Upon the final melting away of the ice this *débris* is uncovered. Such a deposit, which should normally cross the valley as a curved or crescentic belt or ridge, is known as a terminal moraine. As the ice carries different kinds and amounts of *débris* in its different portions, the deposit will not be of uniform composition or uniform thickness. As the ice during seasonal variations moves forward or

retreats irregularly at its margin, such a deposit will have a very irregular or hummocky surface form. The terminal moraine in many valleys in the San Juan Mountains is a belt that crosses the valley and ranges from a few rods to a mile in width. At either side of the canyon this moraine may blend or connect with a lateral moraine deposited at the side of the valley or on the lower slopes, as the ice melted away.

The recognition of the terminal moraine rests upon (1) its topography, which is rough or hummocky, with knobs and kettles; (2) its composition, for it is a mass of stones and boulders of various dimensions, as much as 10 or 15 feet in diameter, intermingled with gravels, sands, and clays; (3) its structure, for in most cross sections it is apparent that much of the material was not carried and deposited by running water, or deposited in standing water, the greater part of the material being unstratified, though within many such deposits there are pockets of stratified sands and gravels; (4) the subangular shapes of the stones; and (5) the scratches or striae found on many of the stones.

When such a terminal moraine is approached from the downstream side it may appear as a rough or hilly belt, usually well wooded, extending across the valley. The stream may have cut but a narrow notch through the moraine, and rapids or cataracts occur at such places. As seen from the upstream side the terminal moraine is not commonly so conspicuous, for on that side the morainic deposits usually become gradually less and less.

RECESSIONAL MORAINES.

When the ice front remains stationary for a considerable time during the general melting and recession of the glacier morainic deposits accumulate at such marginal positions. Those deposits resemble the terminal moraines very closely in topography, material, and topographic relations, and in being frontal, but they are unlike the terminal moraines in that they do not represent the position of the ice front at its maximum advance. Several such recessional moraines may be lodged in a single valley, and at each moraine the stream course may be somewhat constricted. Upstream from such moraines, as from the terminal moraine, the valley floor may be less heavily mantled with glacial drift and so appear broader or more open. Many recessional moraines serve as natural dams, blocking the drainage and causing lakes. In certain of the valleys among the San Juan Mountains there are chains of lakes caused in this way and connected by small streams. The lowering of outlets has drained many lakes that existed for a time after the melting of the ice, and those lake basins now appear as meadows or swampy lands in

the course of the stream. Thus the mountain stream may flow for some distance through a meadow where it has a low gradient and meander there much as rivers of extreme old age wind about in their flood plains. Where such a stream leaves the old lake bottom and crosses the moraine it may have to flow through a narrow gorge, and with falls and rapids in its course it may literally tumble down to the level of the next meadow, again to meander through an old lake bottom and tumble to a still lower level, and so on, until the glaciated portion of the canyon is passed. The constricted courses of the streams just below such lake-bottom meadows have often been selected as dam sites, and the former lake basins as the sites for reservoirs.

LATERAL MORAINES.

When a valley glacier is in place vast quantities of material loosened by weathering, rain work, or streams are carried down the mountain slope and deposited as ridges on the ice but near its margins. Such ridges of *débris* are lateral moraines, and on the final melting of the ice they come to rest at the sides of the valley. They commonly connect at the downstream end with the terminal moraine or with one of the recessional moraines. Upstream they become less and less prominent and die out before the catchment basin is reached.

The lateral moraine commonly resembles a ridge. Its upper surface may have so low a gradient as to suggest an old railroad grade on the canyon wall. There may be a depression between the lateral moraine and the mountain slope, and locally small lakes are held in such depressions. Where a lateral moraine crosses the mouth of a tributary stream ponding may follow and a small lake thus come into existence. Such lakes have commonly overflowed, their outlets have been lowered, and to-day the formerly ponded tributary streams flow through meadows occupying the sites of the former lakes, then cross the lateral moraines, and come into the main valleys.

The position of the lateral moraine on the valley wall represents the minimum elevation of the ice that occupied the main canyon. The ice was certainly somewhat greater in thickness than the elevation of the lateral moraine above the stream channel, for the material of such a moraine is let down perhaps 100 or 200 feet during the melting of the ice before it becomes lodged on the slope.

At some places in these mountain canyons the walls are too steep to permit the lodgment of such lateral deposits, and the material that would otherwise have formed a lateral moraine comes to rest on the floor of the valley. There it does not have a distinct ridgelike form

but is mingled with the general mantle of ground moraine left on the final melting of the ice.

In composition and structure the lateral moraines resemble the terminal and recessional moraines, but they do not contain pockets of stratified materials such as are common in the frontal moraines. The stones in the lateral moraines are more commonly angular than those that were carried near the base of the glacier.

MEDIAL MORAINES.

When a tributary glacier unites with ice in the main canyon the lateral moraine on the upstream side of the tributary glacier joins the lateral moraine of the main glacier and forms a medial moraine. Material so accumulated rests upon the surface of the glacier, but on the final melting of the ice it is deposited on the floor of the canyon. Here and there a distinct medial-moraine ridge now exists on the floor of a glaciated valley. It would seem that as the material of the medial moraine was gradually let down during the melting of the ice, it became distributed or dispersed, and so became a part of a general mantle of drift on the floor of the valley. Short medial-moraine ridges may be present at the junction of a tributary with the main valley.

OUTWASH DEPOSITS.

Downstream from the terminal and recessional moraines vast quantities of sand and gravel are carried out by the waters that come from the melting ice. These sands and gravels load the streams to their utmost capacity and thus commonly lead to the aggradation or building up of the floors of the valleys beyond the position of the ice front. Such outwash deposits are called valley trains. They extend from a few miles to as much as 20 or 30 miles below the terminal moraine. When the glaciers finally melted away and the streams became clearer, having less débris to carry, their velocities were increased and they were able to lower their courses through these loose deposits of sand and gravel. Possibly an uplift of the range helped to quicken their velocities. Thus the stream channels are to-day intrenched below the old flood-plain levels of glacial time, and the remnants of the old flood plains appear as terraces or benches as much as 100 feet above the present streams. At each stage of the retreat of the ice vast quantities of silts were washed out beyond the ice front, so that bodies of stratified sand and gravel may be found at several localities in the valley, but usually they lie just below the frontal moraines.

DEPOSITS OF DISTINCT GLACIAL EPOCHS.

In the San Juan region proof has been obtained of at least three distinct glacial stages during the last long period of erosion.¹ In the earliest of these, which is called the Cerro stage,² the glaciation was the most extensive, and the moraines of this stage have been largely removed. A few scattered remnants, all of which are above or outside of the modern canyons, have been found at several places about the margin of the range.

The glaciers of the intermediate stage, known as the Durango, were intermediate in extent, but they occupied the modern canyons, and their moraines are farther down those canyons and higher on the slopes than those of the last stage. The Durango glaciers were as a rule from 2 to 5 miles longer than the glaciers of the last or Wisconsin stage. Most of the terminal moraines of the Durango glaciers have been removed by subsequent erosion. The lateral moraines remain, and at many places the outwash deposits of that stage may be identified.

The glacial deposits which are of immediate significance in the present discussion are those of the last or Wisconsin glacial stage, which have been described above in detail.

LANDSLIDE DEPOSITS.

When the last glaciers disappeared from the San Juan Mountains the canyon walls were at many places so steep that as weathering and disintegration of the rocks progressed vast quantities of the material slumped off and slid to the bases of the cliffs. The geologic conditions at many places are especially favorable for the development of landslides. Loose or soft formations underlie heavy flows of lava, and as the less resistant formations are weathered out, the heavy load above is undermined, breaks off, and pushes a great mass of the fine material with it down the slope. Again the volcanic rocks become very thoroughly weathered or disintegrated, and such a mass when saturated from heavy rains or from the melting of snow may move or slide down the mountain. Where there is a somewhat impervious layer overlain by loose materials the ground waters collect just above the impervious layer. Such waters may issue as springs at the base of the loose material, but they also serve as a lubricant and hasten the movement of great masses of the overlying rock down the hill. Thus the cliff is forced back and may retreat for

¹ Atwood, W. W., and Mather, K. F., The evidence of three distinct glacial epochs in the Pleistocene history of the San Juan Mountains, Colo.: Jour. Geology, vol. 20, pp. 385-409, 1912.

² Atwood, W. W., Eocene glacial deposits of southwestern Colorado: U. S. Geol. Survey Prof. Paper 93, pp. 14-15, 1915.

many hundreds of feet. At some localities this process has continued until the cliff is a large fraction of a mile back of its former position.

The landslide masses as they accumulate have an exceedingly rough topography. This topography may resemble somewhat that of a glacial moraine, but in contrast to the moraine the individual landslide mass commonly has one longer axis, which makes it ridgelike, and the longer axis or crest of the ridge will be approximately parallel to the cliff from which the mass slid. The landslide materials differ from the glacial deposits in that they are angular, and the individual stones do not have polished and striated surfaces such as are present on the stones of the glacial drift. The landslide masses do not contain so large a variety of stones as the glacial deposits, for their materials must come from the few formations represented in the cliffs above them. The landslide masses are also of smaller extent than the glacial deposits, and the cliffs from which they have come are usually to be seen. There is no assortment of the material in the landslide masses, and in that respect they resemble the deposits left by the melting ice.

Among the landslide masses there are small undrained depressions, and in such depressions lakes may form. Thus the presence of lakes or ponds in the loose deposits of the mountains is not a proof of glacial origin for those deposits. At some places landslide masses check drainage lines and pond the streams, so that lakes have come into existence. Landslides may come from the opposite sides of a mountain canyon and meet on the floor, or they may come with so great velocity from one wall of a canyon that they cross the stream course and ride several hundred feet up the farther slope.

The accumulation of loose angular material at the base of a cliff in the upper portions of a canyon, especially in the great catchment areas, is spoken of as talus. The individual blocks have fallen a few at a time. Locally in these basins, and in a few places farther down the canyons, huge masses of talus material have ridden out or flowed out from the cliffs, and as this process is continued, one mass after another following the same track down the mountain slope, land forms are produced that resemble great mud flows, but they are composed of angular talus blocks. Such deposits have been described as rock streams¹ and are sometimes called rock glaciers, the term implying that the mass was frozen and moved as a glacier, although it was heavily loaded with the angular fragments of rock waste. The significance of the landslide and talus accumulations is referred to in the descriptions of special reservoir sites.

¹ Howe, Ernest, *Landslides in the San Juan Mountains, Colo.*: U. S. Geol. Survey Prof. Paper 87, 1909.

LAKES AMONG THE MOUNTAINS.

By far the greater number of the lakes in the San Juan Mountains are due in one way or another to glaciation. High among the mountains, where ice erosion was intense, small basins were gouged out of the solid rock, and in those basins waters have accumulated. In the valleys below the basins, where deposition predominated over glacial erosion, the deposits of drift have been so irregularly lodged on the floors of the canyons that many undrained areas were left, and in those undrained areas waters from subsequent rainfall have formed small lakes or ponds. In the terminal and recessional moraines the depressions are relatively small, being sometimes appropriately described as "kettle holes," and many of them contain water. Upstream from the great recessional moraines the waters are sometimes held on the floor of the valley awaiting overflow and discharge. In the tributary valleys there are examples of lakes held in by the lateral moraine of the main canyon glacier. Such a lake may in time rise until it overflows, and in cutting its outlet through the lateral-moraine dam it may soon lower its water even to the point of extinction. In a few places lateral moraines retain waters against the mountain slopes, and occasionally a lake may come into existence where two lateral moraines from adjoining canyons meet to form a medial moraine in a small triangular space just above the junction of the lateral moraines. The blocking of drainage by landslides, as has been suggested above, accounts for some of the lakes in the range, such as Emerald Lake, in the valley of Pine Creek, and Lake Santa Maria. Mud flows may be of such dimensions as to block drainage. One of the most remarkable lakes in the range is caused by a mud flow coming across the canyon of the Lake Fork of the Gunnison about 4 miles above Lake City. The ponding of the waters by this mud flow explains the presence of Lake San Cristobal. Glacial deposits and landslides, or other combinations of the loose deposits so commonly found in the mountain canyons, may form undrained depressions. Many of the lakes among the mountains invite investigation by those looking for reservoirs. The outlets may be narrow V-shaped canyons, and the retaining walls may appear high enough so that, if the outlet is blocked, a large supply of water may be readily stored, but the geologic conditions of the areas bordering the present lakes, and especially above their present high-water mark, are of great significance in the selection of reservoir sites.

TORRENTIAL DEPOSITS IN THE LARGE CANYONS.

In addition to the glacial, landslide, and mud-flow deposits in the canyons there are great fanlike accumulations opposite the mouths of tributary streams. The side stream usually comes over a very

steep gradient and brings large quantities of fragmental material or stones, which have been somewhat rounded, and when the gradient is decreased as the tributary reaches the main valley it must deposit its load. The heavier material is dropped first, the stream separates into several distributaries, and more and more of the load is dropped, until in the small streams that result from the continual division of the waters the fine sands and silts are laid down. Such an accumulation has its apex at the mouth of the tributary gorge and slopes radially for nearly 180° from that point toward the bottom of the valley, so that it comes to have a fanlike form. Deposits of this kind from the two sides of the canyon may meet, or a single fan may advance to the farther wall of the canyon, and thus the stream course will be blocked and a lake will come into existence.

STREAM COURSES IN THE LARGER VALLEYS.

The actual channel which the stream follows through a canyon that has been glaciated and affected by landslides, mud flows, and torrential deposits is extremely varied. In places, more commonly in the upper portion of the course, the channel lies on bedrock. Falls and rapids occur where the ice has left a cliff or a very steep slope on the floor of the canyon. Again the stream is diverted to one side or the other because of some huge mass of loose material. The stream course may pass through an old lake bottom or wind in and out among the heavy deposits of a recessional or terminal moraine. Here and there the stream has a meandering course above torrential deposits, or perhaps it has been forced to cut into solid rock far to one side of the canyon by the alluvial fan deposit of a tributary stream. Throughout its course it is usually vigorous. Certain streams have rock walls on one side and at first glance may appear to be cutting into solid rock, but the opposite wall consists of loose material of glacial or landslide origin, and after waters are ponded by a dam at such a location the ponded waters may find easy passage through the loose materials. What appears to be a firm rock gorge has in fact but one wall of firm rock. Or a stream may be in a rock gorge far to one side of a valley, and the preglacial channel may be much lower and in the middle of the valley but filled with debris. The conditions are so variable and the number of possible combinations of the factors that have influenced the location of the stream is so great that the selection of a site for the dam for a reservoir requires a careful examination of the canyon for some distance up and down stream from the proposed site, and a full appreciation of the geologic conditions across the entire width of the canyon just below the reservoir.

The streams of the San Juan Mountains are all youthful. Even after the great deepening accomplished during the three stages of Pleistocene glaciation the streams are lowering their courses. It appears that the mountains are still growing, and the base-level to which the streams are deepening their courses is being lowered in the great mountain mass.

RESERVOIRS.

FARMERS' UNION OR RIO GRANDE RESERVOIR.

The headwaters of the Rio Grande are in the central portion of the range, where the relief is very great and the combined rainfall

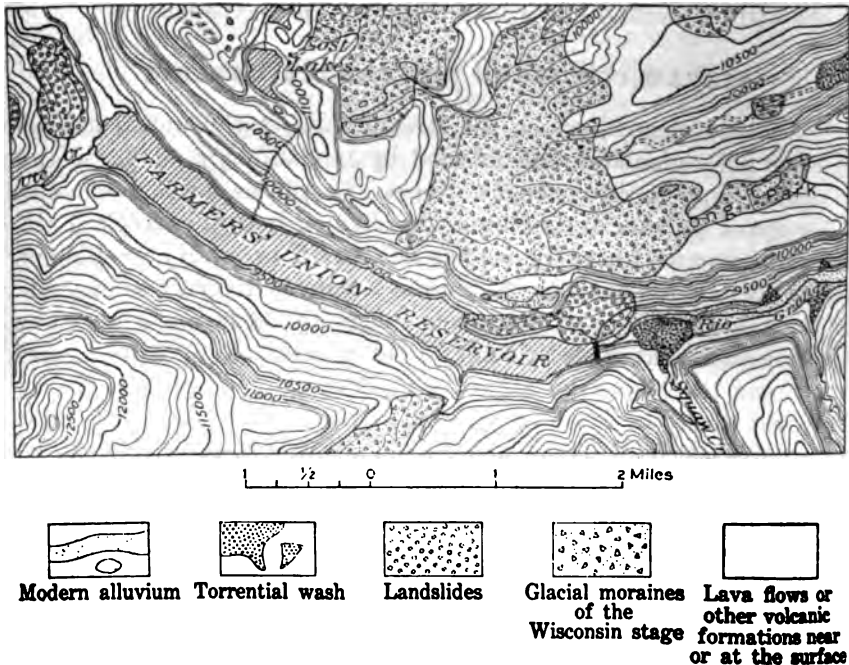


FIGURE 3.—Map of a part of the San Cristobal quadrangle, showing the location and topographic relations of the Farmers' Union or Rio Grande reservoir and the distribution of the loose or unconsolidated formations within the area shown.

and snowfall are so large that each of the streams contributing to this large trunk channel is a vigorous mountain torrent. The portion of the valley that was selected as a reservoir site (Pl. I, A) is in the central part of the San Cristobal quadrangle and extends from the mouth of Ute Creek 7 miles downstream to a point near the mouth of Big Squaw Creek (fig. 3). This portion of the valley of the Rio Grande is south of Lost Lakes and Long Park. The reservoir site may be reached by road most readily from Creede, about 33 miles away.



A. FARMERS' UNION RESERVOIR, LOOKING DOWN THE VALLEY OF THE RIO GRANDE FROM A POINT ON THE WEMINUCHE TRAIL.
View showing the location of the dam and the great landslide area to the north.



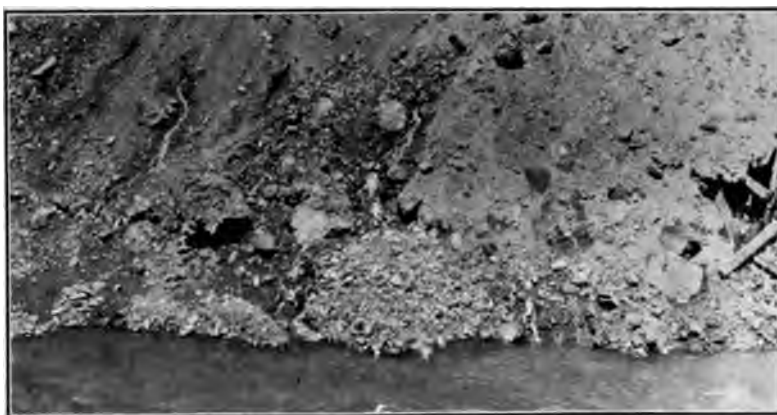
B. DAM OF THE FARMERS' UNION RESERVOIR FROM THE SOUTH.
The spillway appears in the foreground, and the reservoir is to the left. Control gates are near the roadway on the crest of the dam.



C. SOUTH MARGIN OF THE DAM ON THE DOWNSTREAM SIDE, SHOWING LEAKAGE AROUND THE SOUTH END OF THE DAM.
This leakage is through fractured rock. The tunnel opening is near the left margin of the view.



A. NORTH MARGIN OF THE FARMERS' UNION DAM FROM DOWNSTREAM SIDE.
The landslide mass appears at the right, and near the edge of the dam seepage is shown.



B. SEEPAGE THROUGH THE LANDSLIDE MASS JUST BELOW THE FARMERS' UNION DAM.

At the right is the opening of a prospect tunnel.



C. IGNACIO RESERVOIR AND DAM.

The floor of the valley where the waters have been stored was formerly a broad stretch of meadowland. Much of that land had been taken up by ranchmen, who had established their homes. The site of the dam was a narrow place in the stream course just below the broad flat-bottomed portion of the valley. The constriction where the dam has been placed is due to a large landslide area associated with the neighboring cliff at the north. (See fig. 4.) In this cliff there is a thick, heavy flow of lava over a volcanic tuff or breccia.

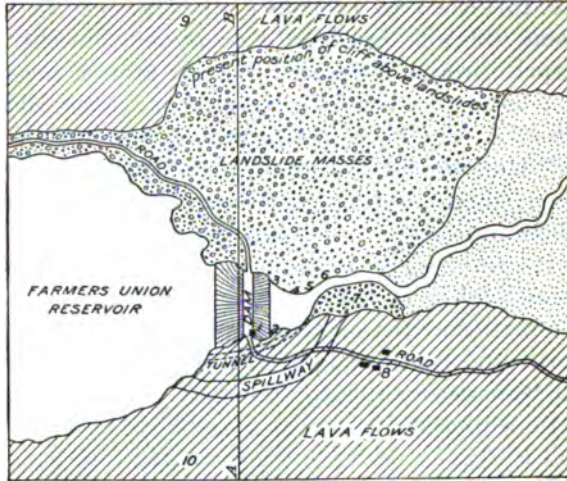


FIGURE 4.—Sketch map showing the geologic conditions immediately adjoining the dam of the Farmers' Union reservoir. 1, Control gates; 2, lower opening of tunnel; 3, 4, 5, 6, places where seepage flows have been noted; 7, angular debris opposite lower end of spillway; 8, construction camp; 9, 10, canyon walls; A-B, position of cross section shown in figure 5.

Such conditions are very favorable for landslides and have caused similar accumulations at many places in the range.

The dam is built of earth and rock and contains a concrete core wall. (See Pl. I, B.) It is about 100 feet high and 400 feet wide and appears to be watertight. The tunnel and spillway (fig. 5) are near

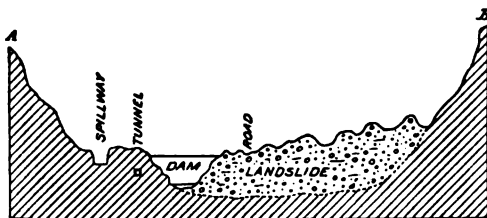


FIGURE 5.—Cross section along the line A-B on figure 4. The diagonal lining simply indicates the extent of the consolidated rock formations, which lie nearly horizontal.

and from a quarter to half a mile in width. The capacity of the reservoir has been estimated at 4,500 acre-feet.

Before constructing the dam some prospecting was done by tunneling into the great landslide mass at the north side of the stream course. Bedrock was not found, and it could not have been expected

the south side of the valley and are cut through rock, which is in place, though somewhat fractured. The level of the spillway permits waters to accumulate in the reservoir to a height of 85 feet just above the dam, and with that height of water there would be a reservoir 7 miles in length

unless the tunneling had gone perhaps a quarter of a mile, so as to reach the north wall of the canyon. (See fig. 5.)

This reservoir has proved to be very serviceable, and the waters are furnished to ranchmen and farmers in the San Luis Valley. Some difficulty has been encountered, however, for the waters have seeped through the landslide mass around the north end of the dam, and have come out into the stream a short distance below the dam. (See fig. 4.) There is one locality where seepage is noticeable from the dampness of the ground, and one other very near the dam (3, fig. 4) where, during September, 1915, there was some water flowing. These indications of seepage were present at a time when the water in the reservoir was very low. In June, 1916, when the waters stood much higher in the reservoir than during the preceding fall and yet far below the maximum possible height, the seepage at both the north and south ends of the dam was notably free. At the south the waters came through the much fractured rock near the lower tunnel opening and issued as a cascade 6 to 8 feet wide. (See 2, fig. 4, and Pl. I, *C*.) More of the fractured rock should have been removed before the dam was constructed. At the north side of the dam small streams were issuing at points marked 3, 4, 5, and 6 in figure 4, through the landslide material. (See Pl. II, *A* and *B*.) Between points 4 and 5 the entire bank was saturated, and waters were flowing freely into the stream. At point 5 an old testing tunnel had become the channel of an underground stream which issued here.

The possibility of checking this seepage by cribbing is under consideration, and every effort will be made by those in charge of the project to prevent this leakage from becoming serious or endangering the success of the project. The landslide mass through which the waters seep appears to consist of very coarse material mixed indiscriminately with finer detritus. If a body of landslide material contains sufficient clay to block up the interstitial spaces and thus form an impervious mass, it may be safely used to retain water. Here the waters have evidently passed through an eighth to a quarter of a mile of this material. It is conceivable that as the waters pass through they may carry and deposit clays in just such places as to block up the subterranean routes, but on the other hand there is evidently the danger of waters going through in such volume and with such velocity that the finer materials in the landslide mass may be washed out and the underground routes become larger and larger.

IGNACIO RESERVOIR.¹

On a high bench west of the canyon of Animas River in the Englemont Mountain quadrangle a large supply of water is held in what

¹ The report on this reservoir is based largely on field work done by Kirtley F. Mather.

is called the Ignacio reservoir (fig. 6). The nearest railroad station is Tacoma, but the reservoir may be easily reached from Durango by road, a distance of about 22 miles. The waters are turned through a great flume into a lesser reservoir near the brink of the canyon wall, and then through a smaller flume down the canyon wall and through a power plant.

The reservoir site is in a country of slight relief and rolling topography, where glacial ice has rubbed off the hilltops and removed

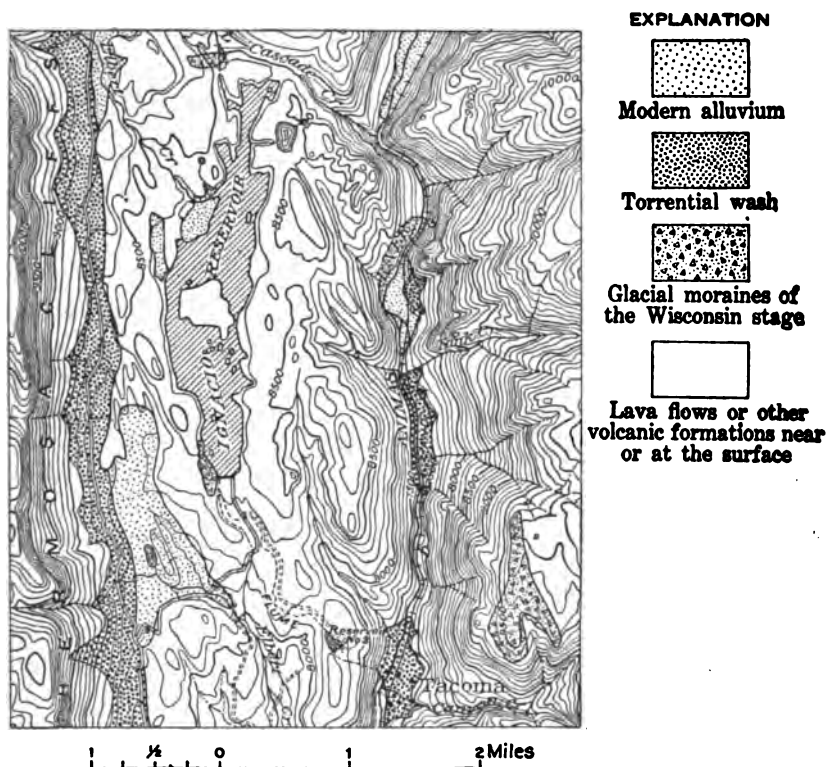


FIGURE 6.—Map of a part of the Engineer Mountain quadrangle, showing the location and topographic relations of the Ignacio reservoir and the distribution of the loose or unconsolidated formations within the area shown. The bench on which the reservoir lies has been severely glaciated, and there is a scattering of glacial drift over most of its surface.

most of the loose material. There is a thin scattering of glacial drift on the bench in the vicinity of the reservoir, and a small area of ground moraine at the west side near the lower end. The area now covered by the waters of the reservoir may have held several small glacial lakes, similar to the ponds and marches on the same bench north and south of the reservoir site.

A dam with a vertical face of about 52 feet in the center was constructed, and several small streams were turned into the basin. The

dam is built of log cribbing with rock fill. (See Pl. II, C.) It is faced with three thicknesses of planking with tar paper between. Ordinarily this dam will hold from 48 to 50 feet of water. No overflow is allowed, for the waters come into the reservoir through flumes and, when necessary, may easily be diverted. The outlet from the reservoir is through a large pipe in the dam, and thence into a 6-foot concrete tunnel through a morainic hill. The intention may have been to rest this dam upon bedrock throughout its length, but as several serious leakages have occurred beneath the dam it appears that the base of the dam was not at all places below the glacial debris.

The dam was not constructed at so great expense or with so much care as many of the more modern structures, and there is always some leakage. It has been reported that twice in the history of the reservoir large leaks have developed. The timbers are now very badly rotted, and the remaining life of the dam would appear to be relatively short.

ROAD CANYON RESERVOIR.

A short distance above the junction of Road Canyon with the canyon of Crooked Creek, in the central part of the San Cristobal quadrangle, there is a small reservoir (fig. 7).

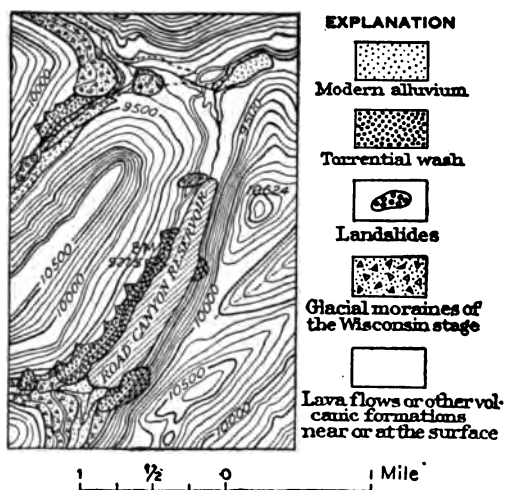


FIGURE 7.—Map of a part of the San Cristobal quadrangle, showing the location and topographic relations of the Road Canyon reservoir and the distribution of the loose or unconsolidated sediments within the area shown.

The valley has a broad, open, flat-bottomed area immediately upstream from a few morainic hills, and it was conceived by persons who wished an extra supply of water that a small dam thrown across the valley at these morainic hills would make it possible to store water. The dam is a mere embankment of earth and stone, of very simple construction, and though it is leaking badly not very much has been invested in it nor very much expected from it. The res-

ervoir is now used as a fish pond. It illustrates the use of a recessional moraine and the meadowland, probably a former lake basin, just upstream from the moraine.

SANTA MARIA RESERVOIR.

Santa Maria Lake is a beautiful body of water resting in a long, narrow trough just west of Bristol Head, 4 miles northwest of Antelope Springs, near the eastern margin of the San Cristobal quadrangle. (See fig. 8 and Pl. III, A.) This reservoir may be reached from Creede by road, a distance of approximately 19 miles.

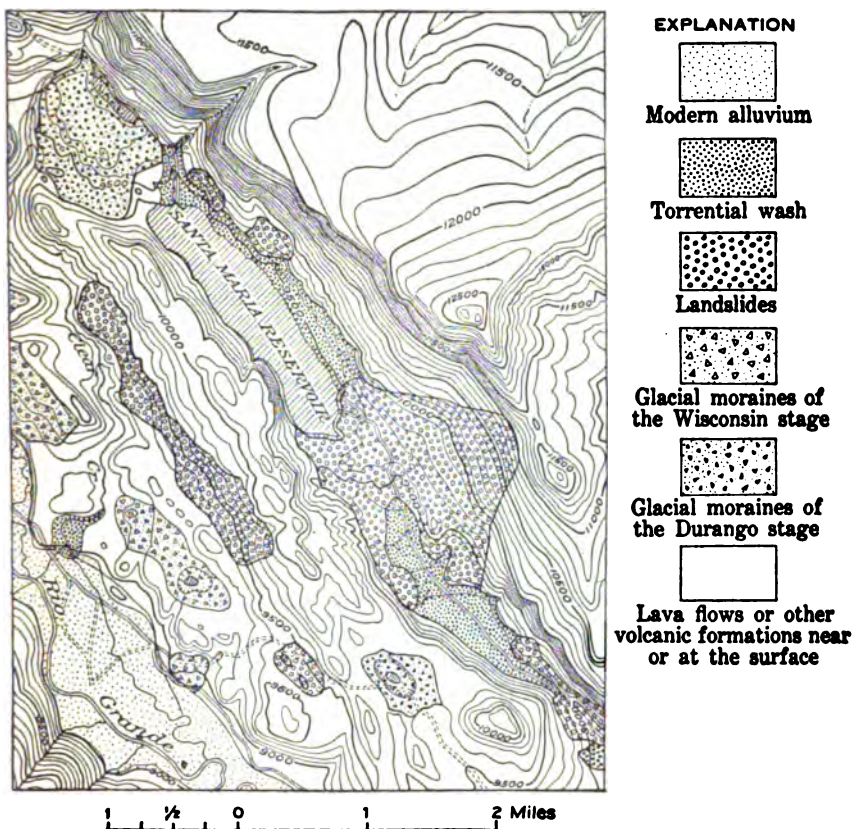


FIGURE 8.—Map of a part of the San Cristobal quadrangle, showing the location and topographic relations of Santa Maria reservoir and the distribution of the loose or unconsolidated formations within the area shown.

The nearly vertical wall of Bristol Head, to the east of the lake, rises over 3,000 feet above the lake level. To the west there is also a steep wall, but this one rises only 800 feet above the average level of the lake. Vast quantities of débris have fallen from the cliff immediately below Bristol Head and partly filled the depression just west of the mountain and south of the lake. (See fig. 8.) There is now a landslide mass at this locality fully 1 mile wide and 500 feet thick, extending for a distance of nearly 2 miles along the axis of the

trough. At the north end of the lake basin there are deposits of glacial drift resting upon bedrock.

To provide for the storage of flood waters in this lake basin an earth dam with a concrete-core wall was constructed at the north end, a tunnel was driven at the northwest corner near the dam, a spillway was built near the dam, and an aqueduct was constructed so that the surplus waters of Clear Creek could be conducted to this basin. (See Pl. III.) The waters of several small streams from the east were also led into the lake basin. The tunnel driven through bedrock near the northwest corner is the outlet of the reservoir, and the waters as they issue from the tunnel follow an open ditch and soon enter Clear Creek, thence flowing into the Rio Grande. These waters are furnished to the ranchmen and farmers of the San Luis Valley. The engineering work and the mechanical construction appear to have been excellent. There is no leaking through or about the dam, and a very considerable head of water has been successfully held. At the south end, where the recent landslide masses form the

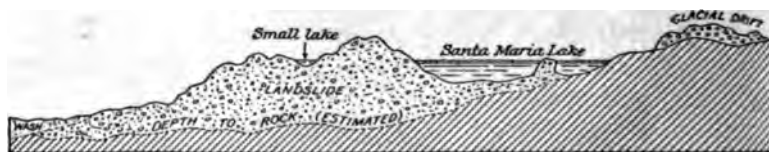


FIGURE 9.—Diagrammatic north-south section through the Santa Maria trough. The actual position of the bedrock surface beneath the lake and beneath the landslide mass south of the lake can not be given accurately.

rim of the lake basin (fig. 9), large quantities of water have seeped through and issued fully a mile and a half to the south, forming a small pond from which, at times, a rushing torrent flows by Antelope Springs and into the Rio Grande. About the south end of the reservoir, however, no signs of leakage appear in the great landslide mass; the surface is apparently entirely unmodified. The water appears at the south margin of this landslide mass not from a single exit, like an underground stream, but probably from general seepage through this huge mass of material. About half a mile below the reservoir there is a small lake or pond in the midst of the landslide masses (fig. 9), and the waters in this small lake have risen and fallen with the waters in the reservoir. It is clear, therefore, that the seepage is quite free as far south as this lake, and the stream already referred to makes it also very apparent that the seepage is free still farther south and, indeed, throughout the mass.

During September, 1915, the waters were being withdrawn from this reservoir. Exploratory work was being carried on at the south margin to determine the nature of the material where the leakage was taking place. This work did not seem to yield significant results,



A. SANTA MARIA RESERVOIR FROM THE NORTH.

Bristol Head is at the left. The landslide mass blocking the reservoir at the south appears just beyond the water. The dam appears in the foreground. At the left in the foreground glacial drift is exposed.



B. SANTA MARIA RESERVOIR DAM FROM THE NORTH.

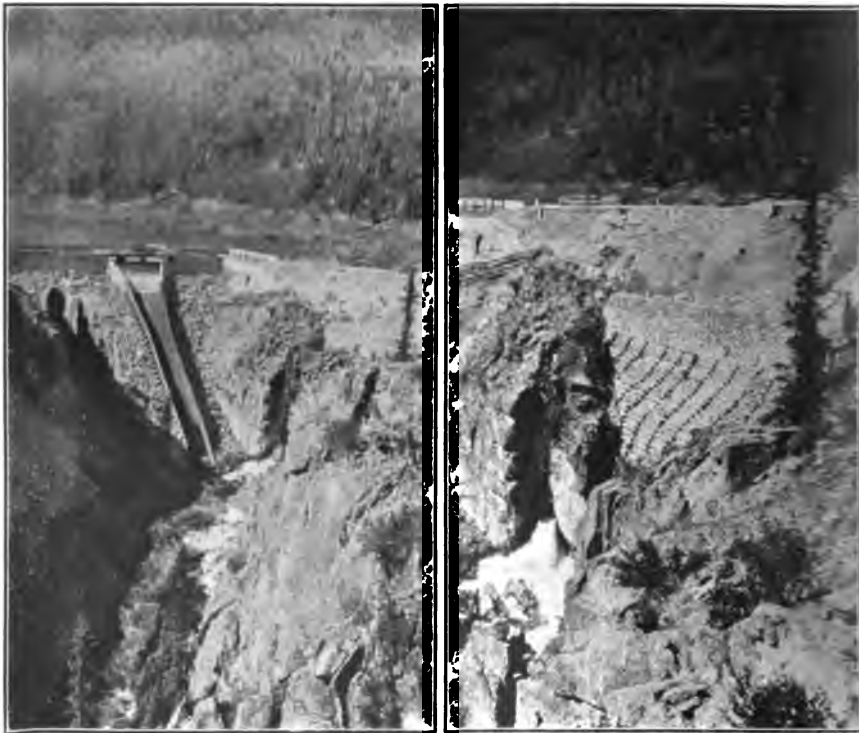
A spillway appears near the left end of the dam. The control gate is regulated from the little house on the dam.



C. OUTLET OF THE SANTA MARIA RESERVOIR.



A. LOWER END OF MOSCA RESERVOIR, SHOWING DAM AND, AT THE LEFT ABOVE THE RESERVOIR, THE FRONTAL MORAINE.



B.

C.

B. MOSCA RESERVOIR DAM AND SPILLWAY, SHOWING THE GORGE BELOW THE RESERVOIR SITE IN THE FOREGROUND. C. TUNNEL OUTLET AT MOSCA RESERVOIR, SHOWING THE CRIBBING PUT IN AFTER THE FIRST BREAK OCCURRED

and could not be expected to, for the nature and composition of a landslide mass can not be judged as well from a few small openings as from the surface. Tunnels and pits might be driven at a hundred places, and the only result could be to ascertain that the mass is heterogeneous detrital material that has fallen from the cliff at the east. It is composed of large and small angular blocks, rocks crushed in the falling and intermingled with some silts and sands. It may even have within it vast quantities of forest growth, which were enveloped in the sliding of the rocks from the mountain, and it may vary in composition greatly within short distances. It is safe to estimate its thickness at 500 feet, and its areal extent is shown in figure 8. Much of the torrential wash just south of this landslide area is interpreted as a mantle over other landslide material.

A serious problem confronts the engineer here, for the south end of the reservoir, where seepage is so generally taking place, has a very irregular outline. The covering of this slope with clay has been considered. One difficulty appears at once in the lack of an abundant supply of clay near at hand, and if this were done it would be very expensive. This reservoir presents a very interesting question. If the waters will not stand at the height desired, why is it that the lake waters have been held at all? It seems possible that the lower portion of the landslide mass may be more dense; perhaps the greater pressure has filled in more of the spaces. Possibly after the waters began to accumulate in this depression behind the landslide mass they leaked freely through to the south for many years. This leakage or seepage, however, passing through 2 miles of material, may have finally, with the help of rainfall and the waters seeping through the ground from above, sealed up with fine materials the passageways that had been used—effecting a sort of automatic puddling. Through this natural process the lower portion of the landslide mass may have become almost if not quite impervious. It is true that before the reservoir project was undertaken there was some water flowing southward toward Antelope Springs. Those interested in the reservoir are justified in hoping that as the waters continue to seep through they may again seal up the underground routes and thus make the landslide mass at the south end a satisfactory barrier. It was believed by those in charge of the reservoir that the leakage during 1916 was less than during the preceding years. If the leakage continues for a term of years without ever causing a real break through to the south it seems that the same processes that made possible the lake may make possible the larger reservoir.

In June, 1916, when this site was revisited, the water was much higher in the reservoir than during the preceding September, and yet the outflow to the south was much less, and the water in the small

lake in the landslide mass just south of the reservoir had not risen with the rise of the water in the larger basin. Perhaps the ground was still frozen beneath the surface at that time early in the season, but if not, the reduction in the amount of seepage would seem to have removed all fear of serious trouble from that source. There are no other serious difficulties associated with this project.

MOSCA RESERVOIR.

By J. FRED. HUNTER.

The dam of the Mosca reservoir project was built in 1913-14 to impound and store the flood waters of the Beaver Creek basin for

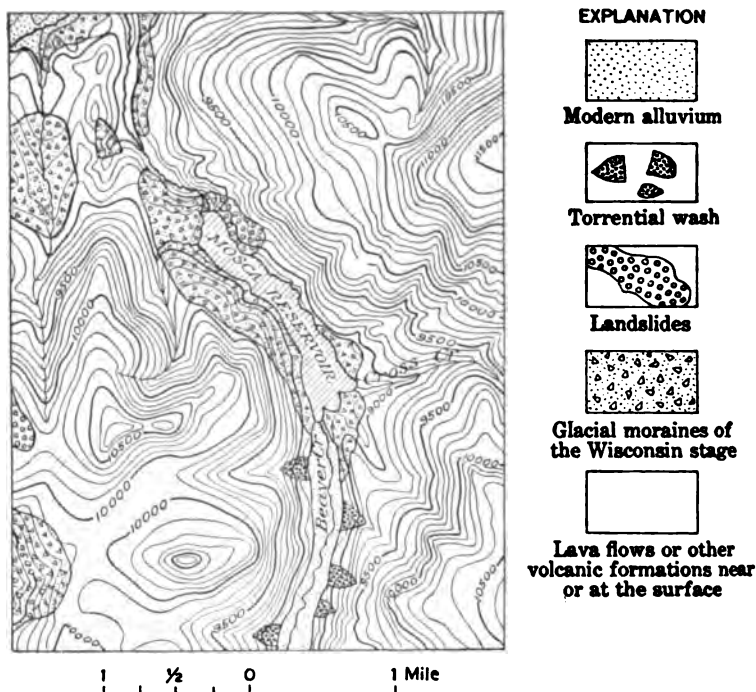


FIGURE 10.—Map of a part of the Creede quadrangle, showing the location and topographic relations of the Mosca reservoir and the distribution of the loose or unconsolidated formations within the area shown.

the irrigation of lands in San Luis Valley. It is 2 miles from the junction of Beaver Creek with the South Fork of the Rio Grande and 5.6 miles in an air line west of south (about 7 miles by road) from the town of South Fork, on the Creede branch of the Denver & Rio Grande Railroad. (See fig. 10.) The dam is built across a narrow gorge at the lower end of a long stretch of meadow land known as Beaver Creek Park and is of sufficient height to back water for approximately $1\frac{1}{2}$ miles. The valley for this distance has a flat allu-

vial floor several hundred feet in width, from which the slopes rise rather abruptly on either side from 8,800 feet above sea level to more than 10,500 feet.

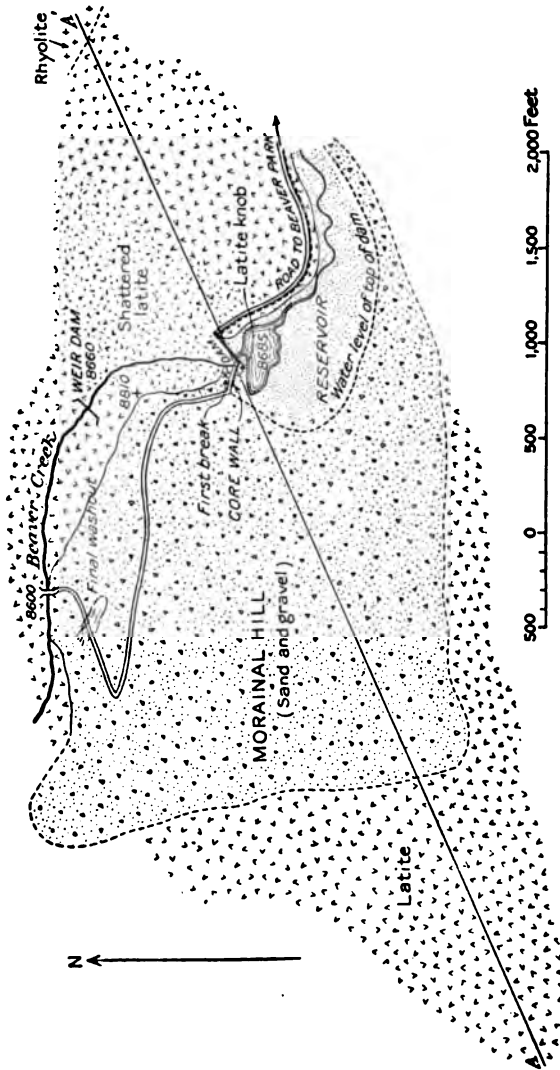


FIGURE 11.—Sketch map of Mosca reservoir project and environs, showing approximate boundaries of geologic formations. (The exact location of the core wall is not known.)

The distinctive feature of the site, which has attracted the engineer, is the abrupt closing in of the broader valley. A low, sparsely timbered morainal hill with gentle slopes and flat or rolling profile, rising 200 feet or more above the meadow, affords a natural barrier to the valley, crowding Beaver Creek against the foot of the steep north slope, where it is restricted to a narrow, V-shaped canyon.

At the entrance of this canyon is the dam, which is of concrete, reinforced by batter masonry on the downstream side, and is 85 feet

high at its breast and 210 feet long at the top. It is built between walls of considerably shattered volcanic rock of the variety known as quartz latite. However, west of the dam this rock continues for only a short distance, giving way to unconsolidated glacial débris as indicated in the profile section of figure 12. (See also Pl. IV.) This volcanic rock forms a knob between the canyon and the extensive deposit of sand and gravel which rests against and on it, filling a former channel in the harder rock to an unknown depth. The outlet of the reservoir is by a channel driven through this knob of latite in a northwesterly direction for approximately 40 feet.

The conditions can be best understood from the sketch of the dam and its environs (fig. 11) and the profile section across Beaver Creek just below the reservoir (fig. 12). These drawings are intended to present the relations graphically rather than to afford accurate maps of the locality. It should be understood that the contact between the volcanic rock and the gravels in the profile of figure 12 is hypothetical except for the points where it meets the surface.

The Mosca dam project is of especial interest as a demonstration of the inefficiency of a barrier of a certain geologic type to retain water. Several attempts have been made to fill the reservoir, but in each attempt the porosity of the barrier hill has led to leaks and to serious washouts.

The first of these developed around the southwest end of the dam (see Pl. IV, *C*), and later ones resulted in a large washout along the road 1,500 feet to the northwest. (See fig. 11.)

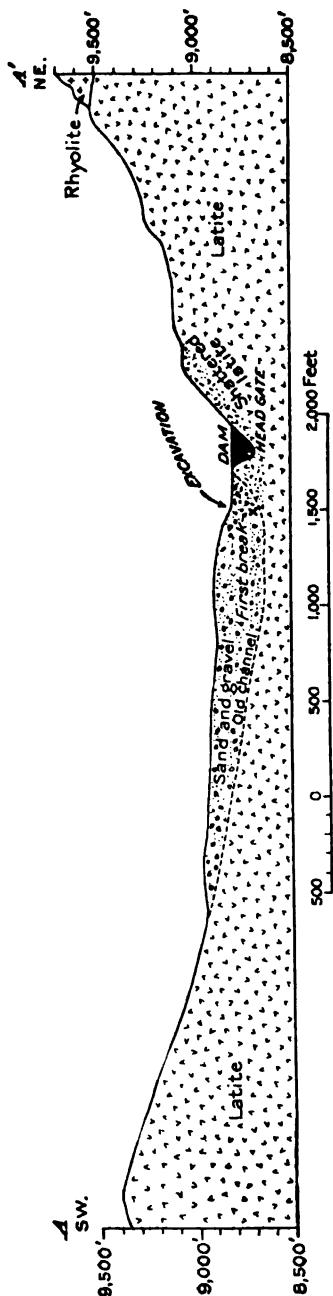


FIGURE 12.—Profile section across Beaver Creek at Mosca dam, along line A-A' of figure 11.

Although the physiographic features that led to the selection of the dam site are rather obvious, the peculiar geologic conditions that make it undesirable and have resulted in its failure to retain water are apparent only after more detailed study. It is the purpose of this section to describe briefly the character of the formations and their structural relations; also to discuss the causes of failure and certain suggested remedies.

The bedrock in the vicinity of the Mosca dam is entirely of one kind, which may be best classified as a quartz latite. This is the prevalent type of rock in the region and has an extensive distribution along the lower slopes of Beaver Creek and throughout the length of the South Fork of the Rio Grande. It is white or pinkish gray, is of easy fracture, and consists of scattered crystals of feldspar, biotite, augite, and orthoclase, less than 2 millimeters in diameter, set in a rather dense and obscure groundmass composed chiefly of an indistinctly polarizing aggregate, feldspar microlites, tridymite, and ferritic material. The lava has picked up a few angular fragments of andesites and other rocks in the process of its eruption, and where weathering has taken place small quantities of calcite, chlorite, and limonitic minerals have been developed. This latite has been poured out as molten lava, cooled, buried by younger flows, and later exposed by stream erosion.

The rock knob at the southwest end of the dam and the immediate rock mass at the other end of the dam have been interpreted as of landslide origin. This would account for the hillside topography shown in Plate V, *B*, and for the shattered condition of the dock at both ends of the dam. A serious leakage has occurred around the northeast end of the dam.

A close examination of the nature of the morainal deposits west and north of the bedrock knob shows that the faith which has manifestly been reposed in them is hardly warranted. A small cut west of the dam and above the road reveals its porous, unconsolidated character and shows that it consists of irregular stratified sand and fine gravel.

A better exposure has resulted from the washouts along the road some 1,500 feet to the northwest. Here nearly 50 feet of section shows alluvial layers of irregular, cross-bedded coarse and fine sands, grits, gravels, and conglomerates.

Partial section of material exposed in the largest washout from Mosca reservoir.

	Feet.
1. Coarse conglomerate	10
2. Rather fine, homogeneous, unconsolidated sand of dark-brown color, saturated with water.....	10
3. Black sandy member with thin layers of volcanic pebbles, largely black glass, becoming coarser at base.....	15±
4. Sandy member, similar to No. 2, with thin lenses of grit and fine gravel.....	10

The pebbles of the conglomerate are all of volcanic origin, such as might be derived from the Beaver Creek basin, are well rounded, and range in size from fine grit to boulders 10 inches in diameter. The coarser boulder beds show more irregular bedding and were doubtless deposited by torrential stream wash, whereas the sandy members are even bedded and suggest delta or pond deposits. No striations could be discovered on the boulders.

An examination of the hill above the dam reveals at once its morainal origin, for the country west of the dam for a distance of half a mile, included within the 8,900-foot contour as shown on the Creede topographic map, is of abnormal configuration, is poorly drained, and is covered with a thick mantle of boulders and wash.

Save for a small V-shaped area of till on the west wall immediately north of the latite knob, the waters of Beaver Creek now travel through a canyon of latite as far as the road bridge at the 8,600-foot contour crossing. At that place the morainal débris comes down to the creek and for 120 to 150 yards makes the south side of the stream channel. Below this a wall of latite rises gradually downstream. From the west end of the reservoir to this point, just below the bridge, an earlier, premorainal stream probably flowed through a fairly straight channel, now filled with glacial material. It was by way of this same route that the underground seepage waters from the reservoir found their escape. Below this point the earlier Beaver Creek channel coincides with that of the present stream.

The unconsolidated deposits here mentioned are believed to represent the accumulations of débris gathered by great glaciers descending from points high in the adjacent mountains of the Beaver Creek basin. After the retreat of the glaciers and after the South Fork had established itself in a deepened channel, Beaver Creek commenced the task of cutting another channel, releasing its impounded waters, and cleaning its valley of the vast accumulations of débris. In this process it seems to have found its easiest path to be coincident with its earlier channel except in a stretch below the Mosca dam as far as the road bridge. Here, by reason of the immense accumulations, it was forced to cut an entirely new course through the detrital material and into the harder volcanic rocks, forming the present

gorge. This work was the more easily done by reason of the immense amount of unconsolidated gravel and boulders available in the upper course of the basin, which increased the abrasive power of the stream.

Many of the principal facts relating to the Mosca reservoir were established on the ground; other details have been acquired from fragmentary reports of persons who have knowledge of the project. With all the data so far available it is possible to construct an incomplete history of the project.

On the completion of the dam, in the summer of 1914, the head gate was closed and the filling of the reservoir commenced. The rising water brought an increasing pressure against the very porous gravel barrier which is really the major feature in the damming of the valley. Immediately the water began to seep around the latite knob at the southwest end of the dam, as indicated in figure 2—the knob which projects for about 90 feet above the valley floor through the accumulations of sand and gravel.

Before the reservoir was two-thirds full the fine till began to give way and to wash out so that it became necessary to construct cribbing filled with broken rock along the upstream limb of the V-shaped contact of the latite and gravel. (See Pl. IV, *C*.) A core wall about 120 feet in length has been built in a westerly direction from bedrock at the contact of the moraine with the latite. This contact is said to dip 45° along the line of the wall.

When the water was allowed to rise in the reservoir a second time a much larger leak developed at a point some 1,500 feet from the reservoir, on the slope 100 yards south of the road bridge. This leak proved to be even more serious than the first and quickly developed into a disastrous washout. The water escaped so rapidly and abundantly that the soft, unconsolidated sands and gravels are described as having been catapulted out of the hill, leaving a ravine as much as 20 feet deep and being washed down the slope to the valley bottom to form a large torrential fan. Although the beds at once became saturated and seepages appeared over nearly the entire slope, the bulk of the water is reported to have come out at about 20 feet below the bottom of the reservoir. This leakage proved so great and serious that it was necessary to reopen the head gate at once and relieve the pressure from the head of water in the reservoir. For several months during the winter of 1914–15 no effort was made to use the dam. In the spring of 1915 an attempt was made to puddle the reservoir west of the dam but without success.

The essential causes of the failure of the Mosca reservoir to retain water are clearly the presence of the buried channel and the unusually high porosity of the sands and gravels that fill it. This porosity is shown by the fact that at the time of the examination the

exposures in the vicinity of the larger washout were saturated to a high degree and the sands and gravels were still in the process of draining, although the water was out of the reservoir save for the normal flow of Beaver Creek through it. Furthermore, the surface waters have no doubt taken advantage of the porosity and looseness of the material and have established more or less definite subterranean channels, as is indicated by the number of permanent and periodic springs scattered here and there over the area. The intakes of the subterranean channels are represented by smaller, partly choked openings near the base of the gravel embankment of the reservoir a short distance west of the latite knob. Flow lines of sand and débris into these holes indicate the passage of water out of the reservoir. In view of these conditions it is not surprising that when the water rose in the reservoir, exerting an unusual pressure against the morainal barrier, the gravels at once became saturated, subterranean channels were established, and the breaks resulted. It seems clear that the morainal deposits, in this locality at least, are not competent to retain a large head of water.

In view of the large sum of money already expended the further utilization of the project became a very serious question with the promoters, stockholders, and engineers. It is not within the province of this report to offer an opinion as to the feasibility of diminishing the leakage to such an extent that the reservoir could be used. However, it is very evident that to attempt to hold water in the reservoir without reinforcing the morainal end of the dam would be simply to invite disaster. Indeed, from past experience it is not improbable that the entire hill between the reservoir and the washout would be tunneled by the rush of water, and possibly the buried channel would be exhumed. Puddling of reservoir levees and embankments has been found practicable in many places but is only questionably applicable to this reservoir because of the absence in the vicinity of silt, clay, or fine shaly material with which to line the embankment. Revetments of masonry, concrete, macadam, asphalt, or logs have been suggested but should be adopted only after careful estimates by the engineers as to their cost and practicability. It would be highly advisable as a preliminary step to make a careful survey in an effort to ascertain the lowest point in the reservoir at which leakage begins. From the meager geologic examination so far made it seems probable that the leaks may have originated in the floor of the reservoir itself. If this is found to be the case, a revetment of the embankment alone would not be sufficient, but it would have to extend for greater or less distances out upon the floor of the reservoir, amounting to many hundreds of square yards.

SUPPLEMENTARY NOTE BY W. W. ATWOOD.

When the writer visited the Mosca reservoir in June, 1916, a group of engineers were at work trying to prevent the leakage. On the east side of the dam, where the leakage had been very great, they were drilling holes at intervals of 10 feet and to the depth of 90 feet. Farther south the interval between the holes was to be 20 feet. Into these holes they were forcing cement under a pressure of 40 pounds, in the hope that the cement, spreading through the fractured rock, would seal up all openings. The holes were drilled from the roadway, and 90 feet took them nearly to the bottom of the reservoir.

Another project was also under way. A tunnel had been driven into the moraine a little to the north of west from the cribbing near the west end of the dam. This tunnel had been driven 180 feet, and it was proposed to take it 135 feet farther. The base of the tunnel is 13 feet below the reservoir gate and about 7 feet above the base of the reservoir. At intervals of 6 feet perforated iron pipes were driven from the roof of the tunnel upward through the sands and gravels, in the hope that the waters seeping into the moraine would enter the small holes in the pipes and be led off by the tunnel into the stream below the dam, thus preventing the seepage from passing through the moraine and washing it away.

Early in the season, before this work had been completed, the gate was closed and the water was allowed to rise in the reservoir. Before it reached the desired height a serious leak occurred near the east end of this tunnel. It appeared that not all the escaping water was accommodated by the pipes then in place, and that some ran directly into the tunnel. This water washed with it sands and gravels, and a large mass fell and broke down that end of the tunnel. The engineers concluded that the timbering must be made exceedingly strong and that the work must be carried much farther into the hill before the water was again allowed to rise. It was their intention to complete the work thus outlined and in the spring of 1917 to make another trial. The device put into the moraine was called a "drip curtain."

TERRACE RESERVOIR.

The Terrace reservoir lies in the valley of Alamosa Creek, in the foothill belt of the San Juan Mountains in Conejos County, and may be easily reached by road from Monte Vista or Alamosa. (See Pl. V, A.) The "terrace," or broad alluvial land that receives the water from this reservoir, is a torrential fan spread out in the San Luis Valley beyond the base of the mountains. From the apex this fan slopes radially to the northeast, east, and southeast. Near the apex the slope is 75 feet to the mile. Farther east, lower on the fan, the slope is 10 feet to the mile. This fan form is admirably adapted to irrigation, as the main supply canal may be brought to the apex of the fan and lateral canals constructed to the right and left so as to supply waters over the entire area of the deposit. Near the apex the alluvial material is coarse and in places bouldery, but farther from the mountains it is finer and very suitable for agriculture. Thousands and thousands of sheep that spend their summers high on the mountains are brought to these lowland fields for the winter.

and fattened. Thousands of hogs are here fattened for market. During the winter horses and cattle that have been on the range during the summer are brought into the irrigated fields and

The dam is 5 miles above the mouth of the canyon. It is an immense earth dam, reported to be the largest in the United States

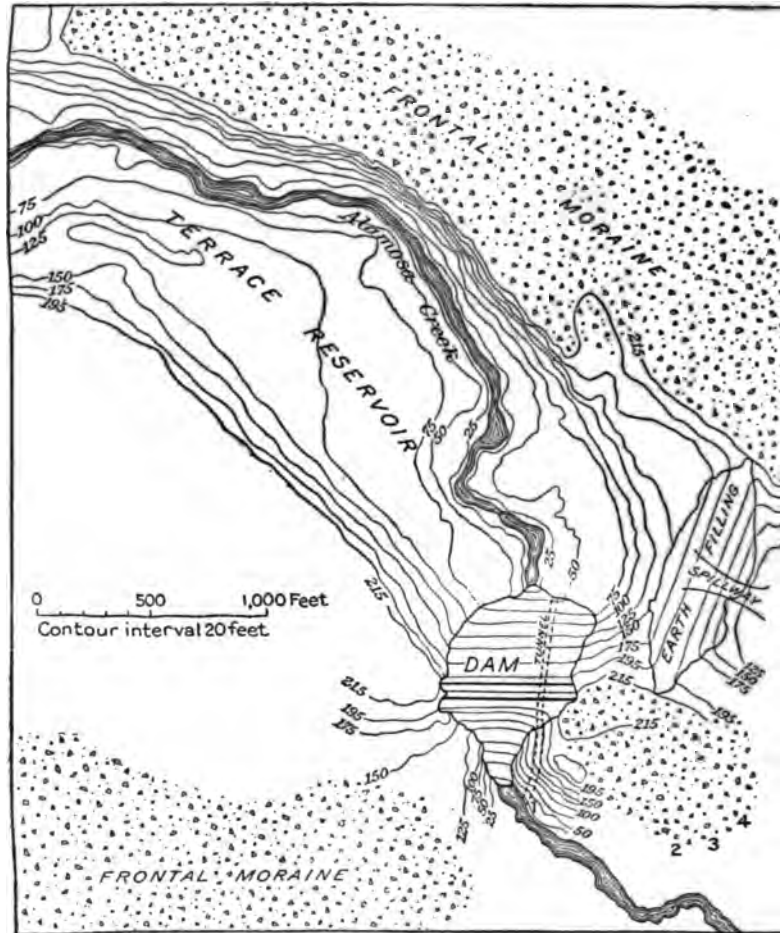


FIGURE 13.—Sketch map of the lower end of the Terrace reservoir, showing the distribution of the frontal moraine that determined the location of the dam and reservoir site. 1, Lower-opening of tunnel; 2, 3, 4, seepage vents. Contours have been taken from a map in the office of the State engineer of Colorado.

is 165 feet high, and its length at the base along the course of stream bed is 1,075 feet. A tunnel driven through hard rock (fig. 13) is 1,000 feet long, 7 feet high, and, on the average, 12 feet wide. The discharge, under a 70-foot head, is estimated at 1 cubic foot per second.

The dam is constructed in a narrow rock gorge just downstream from a broad, open portion of the valley. (See Pls. VI and VII.)



A. TERRACE RESERVOIR.

The dam is at the right, and the earth filling and spillway are in the middle ground beyond the water. The low hills at the left form a part of the moraine and rest upon a lava flow.



B. MOSCA RESERVOIR SITE.

This view shows the location of the dam, the cribbing where the first break occurred, the landslide mass at the left end of the dam, the great moraine at the right end of the dam, and the narrow gorge below the reservoir site.



A. TERRACE RESERVOIR DAM FROM THE NORTH.



B. CREST OF TERRACE RESERVOIR DAM.
The gate in the tunnel is controlled from the house on the dam.



C. TERRACE RESERVOIR DAM FROM BELOW.
The spillway here shown was used during the construction of the dam.

In figure 13 the general topography and geologic conditions of the area surrounding the site of the dam are given. The glacial moraine at the north, east, and south indicates that for some time the front of a great alpine glacier rested at just this place in the valley of Alamosa Creek. While the ice was present the drainage must have found an outlet in part from beneath and in part from the surface of

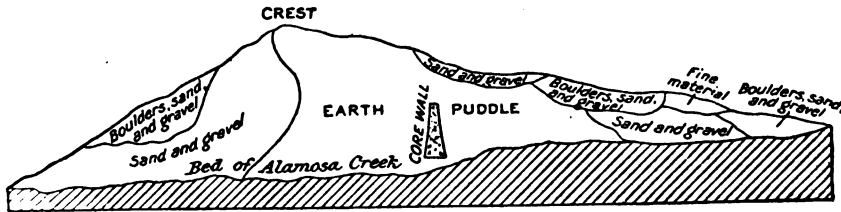


FIGURE 14.—Cross section of the earth dam of the Terrace reservoir, based on data furnished by R. I. Meeker, engineer in charge, 1916.

the glacier. The heavy morainic deposit completely filled the pre-glacial route of the stream, and as the ice retreated the water issuing from the melting glacier found a route at the south margin of the valley and there cut a narrow gorge in rock (Pl. VII, C). This gorge, due to a disarrangement of drainage caused by the glacier and the moraine it left, was chosen for the site of the dam because of the firm rock walls on either side. In constructing the dam a concrete baffling wall was firmly cemented to the sides of the gorge, and a concrete core wall 70 feet high was also constructed. (See figs. 14 and 15.) The earth material used was chiefly of glacial origin, and a gigantic puddle was formed in the central portion of the gorge about the core wall, so that an abundance of fine material might settle in that portion of the proposed dam.

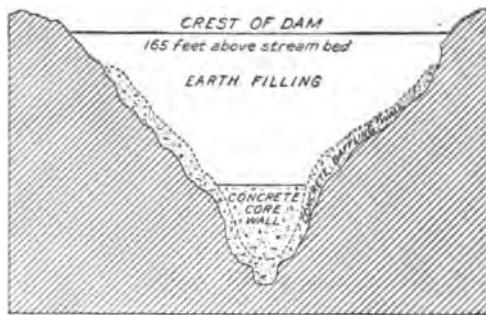


FIGURE 15.—Cross section of the gorge in which the earth dam of the Terrace reservoir has been placed, based on data furnished by R. I. Meeker, engineer in charge, 1916.

A lower earth dam or filling was constructed a little to the north-east and above the former channel of the stream. Through this filling a spillway has been provided.

This reservoir draws upon a large drainage area. Alamosa Creek and its tributaries head far back in the high mountain area to the west, and there is usually an abundance of water available. At points 2, 3, and 4 on figure 13 large leakages, which appear as springs on the

loose glacial débris, but when seen in the summer of 1916 the water was issuing in a remarkably clear condition. Those in charge of this reservoir report that the seepages began soon after the water was first allowed to rise and have occurred during each succeeding season. The leaks suggest the danger of large subterranean routes through the glacial material, perhaps at the base of the drift and on the rock surface, but as they have continued for several years without producing any serious damage there seems to be no immediate reason for fear.

LA JARA RESERVOIR.

The La Jara reservoir is on La Jara Creek, in Conejos County, and may be reached most easily from Monte Vista. It was constructed in 1909. The geologic conditions of the area surrounding the lower end, where a dam has been placed, are shown in figure 16.



FIGURE 16.—Sketch map showing geologic conditions of the area immediately surrounding the lower end of the La Jara reservoir, based in part on a map in the office of the State engineer of Colorado.

At the north there are dense lava flows forming the gentle slopes of this foothill region, but at the south there is a heavy frontal moraine of an ancient glacier. The ice appears to have advanced from the high mountain region a little to the south of west and, on reaching this lowland country, deployed northward so that La Jara Creek was forced to flow between the margin of the ice and the lava hills. On the retreat

of the ice the stream cut a narrow gorge in the margin of the moraine, where the present outlet of the reservoir is placed.

Two dams were constructed of the surface débris of glacial origin and the weathered volcanic rocks. One is 759 feet long and 51½ feet high. The other and more northern one is 23½ feet high and 495 feet long. The slope of these earth dams is 3 to 1 on the upper side, facing the reservoir, and 2 to 1 on the lower side. Their crests are about 15 feet above high water and 12 feet wide. A spillway has been provided through a low trough just north of the glacial moraine, by a route that was probably used by the stream when the ice was present. The estimated area tributary to this reservoir is



A. GENERAL VIEW OF TERRACE RESERVOIR DAM FROM THE SOUTH.

The rock walls of the canyon appear, in the middle ground is the spillway used during the construction, the house from which the gates are controlled appears on the dam, and the line of hills in the distance next below the sky line is a portion of the great frontal moraine.



B. OUTLET OF TERRACE RESERVOIR TUNNEL



C. POSTGLACIAL GORGE BELOW TERRACE RESERVOIR.



A. LA JARA RESERVOIR DAM.
Morainic material appears in the foreground.



B. LA JARA RESERVOIR.
The moraine shows in the foreground. The distant hills are composed of lava flows.



C. TUNNEL OPENING IN THE LA JARA DAM.

50 square miles, and the claim is made for the full capacity of the reservoir, estimated at 20,000 acre-feet. The water is taken from La Jara Creek and all its tributaries, including Lost Creek, and may be used for domestic purposes, irrigation, power, or any other beneficial purposes.

This reservoir has become the property of the Terrace Reservoir Co. and is used as an "exchange reservoir." Water is taken from Alamosa Creek, and in return the La Jara water is carried into that creek a little farther downstream to satisfy old priorities. This exchange is permitted by a State statute.

There is some seepage through the dam, but it has never become dangerous. The reservoir as constructed will hold much more water than is available. To the south of the great frontal moraine, and from a quarter to half a mile south of the reservoir, a number of large springs have developed, and those who are familiar with the history of this project report that these springs have appeared since the damming of La Jara Creek, and that they are affected by the height of the water in the reservoir. This would indicate that the great morainic mass is not sufficiently compact to hold all the water collected in the reservoir to the north of it. The water presumably sinks through to the base of the glacial débris and follows the rock surface beneath.

Plate VIII gives good general views of the reservoir, of the larger dam where the outlet is located, and of the massive moraine south of the reservoir.

PROPOSED RESERVOIR IN CLEAR CREEK.

The upper portion of Clear Creek is in the north-central part of the San Cristobal quadrangle. A short distance above the point where the stream turns toward the southeast to flow to the Rio Grande the valley is constricted, as shown in figure 17.

The constriction is due in part to rock, but the rock is overlain by glacial débris. Upstream the valley is broad, open meadowland. Before construction work is begun a detailed study of the geology at and near the dam site should be made. The clearing away of the glacial débris and all loose rock and the construction of the spillway in solid rock should make this project safe so far as leakage is concerned. The drainage area that furnishes water to this creek, however, is relatively small.

PROPOSED RESERVOIR ON SOUTH FORK OF CLEAR CREEK.

The South Fork of Clear Creek is nearly due west of Santa Maria Lake, in the central part of the San Cristobal quadrangle (fig. 17). The upper part of the valley is broad and open, and its floor is an extensive meadowland. Near the point where the stream turns south-eastward the valley is rather narrow, and the narrow portion has

been thought of as a possible site for a dam, above which the waters would collect on the present meadows. This is a very unfortunate selection for a reservoir site, as the deposits at the proposed site are of glacial and landslide origin. It is extremely doubtful whether that material would hold in more than a low head of water. The fate of the Mosca reservoir, in the Creede quadrangle, should be a

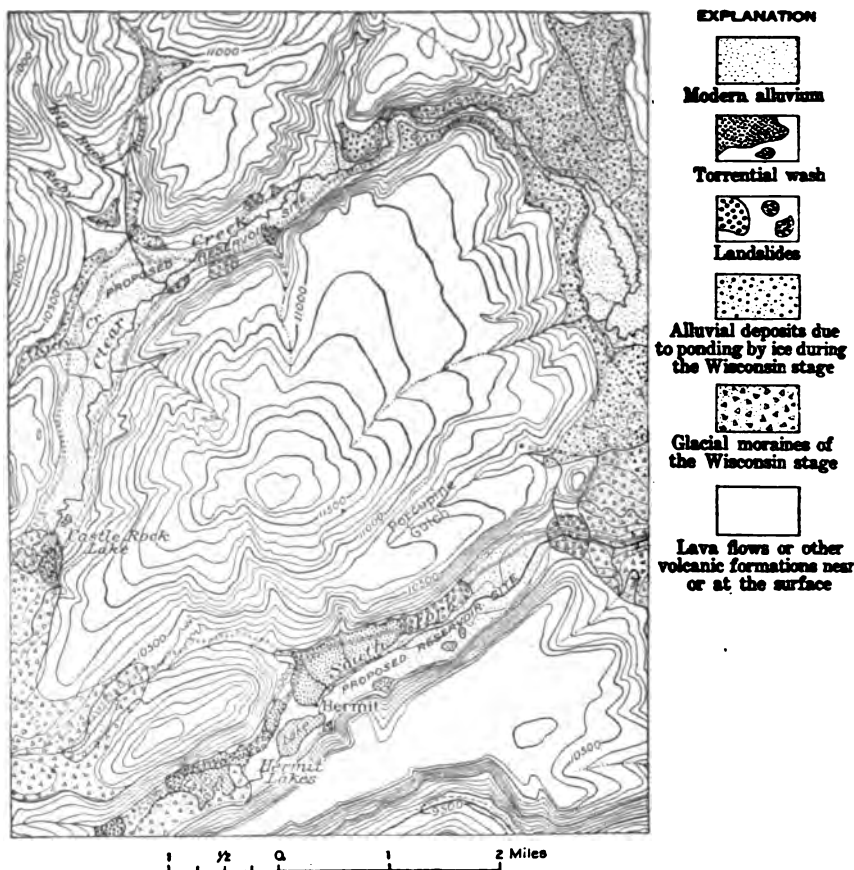


FIGURE 17.—Map of a part of the San Cristobal quadrangle, showing the location and topographic relations of the proposed reservoir sites in Clear Creek and South Fork of Clear Creek and the distribution of the loose or unconsolidated formations within the area shown.

sufficient warning against undertaking a project under geologic conditions such as exist near the mouth of the South Fork of Clear Creek. Furthermore, the surplus waters of that fork are exceedingly small, and the project would certainly not justify large investments. Before construction work is begun a detailed geologic study should be made of the land immediately adjoining the proposed site for the dam.

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